A MANUAL . .

OF

BOTANY

BOOKS = HOLE, R. S.

E J Butler

With the author's compliments
8/XI/09

# ERRATA.

Page 11, lines 14-15, *for* are called stolons *read* is called a stolon.
,, 27, line 19, *for* plant ssuch *read* plants such.
,, 34, line 24, *for* lormed *read* formed.
,, 34, line 25, *for* farge *read* large.
,, 41, line 8, after *Dolichandrone* delete comma.
,, 41, line 9, from below, *for* typica *read* typical.
,, 50, line 1, *for* ligutiform *read* liguliform.
,, 50, footnote, *for* jurnished *read* furnished.
,, 55, line 14 from below, *insert* comma *after* one.
,, 57, marginal note, *for* Diagrams Floral *read* Floral Diagrams.
,, 58, marginal note, *for* S ed *read* Seed.
,, 63, line 3, *after* falling off *insert* or fading.
,, 70, line 11 from below, *for* Alcurene *read* Aleurone.
,, 81, footnote, line 4 from below, *for* =a wrinkle) *read* (=a wrinkle).
,, 89, line 2 from below, *for* orophyll *read* chlorophyll.
,, 96, marginal note, *for* Wtaer *read* Water.
,, 107, line 4 from below, *after* side *delete* comma.
,, 109, line 4 from below, for *i.e.* read *e.g.*
,, 111, line 15, *for* A *read* As.
,, 111, line 25, *after* These *insert* are.
,, 111, marginal note, *for* ertilisation *read* fertilisation.
,, 135, line 14 from below, *for* forest *read* forests.
,, 154, footnote, *for* Physiiogy *read* Physiology.
,, 156, line 17 from below, *for* asexua *read* asexual.
,, 180, line 16, *for* ha s *read* has.
,, 227, marginal note, *for* Plant *read* Plants.
,, 239, line 3 from below, *for* mong *read* Among.
,, 244, marginal note, *for* Wesern *read* Western.
,, 245, marginal note, *for* Forest *read* Forests.
,, 249, line 23, *for* of *read* or.
Index, Page ii, *after* Bark internal, *for* 80 *read* 79.
,, ,, *after* Bast internal, *for* 80 *read* 79.
,, ,, X, *after* Internal bark. *for* 80 *read* 79.
,, ,, xviii, *after* Stomata, *for* 48 *read* 84.
,, ,, ,, ,, Stool-shoots, *for* 71 *read* 171.
In Explanation of Figures, Plate IV, last line, *for* pedately-parted *read* pedately-divided.
,, Explanation of Figures, Plate VI, line 5 from below, *for* branche *read* branch.
,, Explanation of Figures, Plate XVII, line 9, *for* wood parenchyma-bearing *read* wood-parenchyma bearing.
,, Explanation of Figures, Plate XVII, line 11, *for* vessel *read* tracheid.
,, ,, ,, ,, ,, ,, lines 12 and 14, *for* trachea *read* tracheid.
,, ,, ,, ,, Plate XIX, line 2, *for* Ureao-spores *read* Uredo-spores.

# A Manual of Botany

FOR

INDIAN FOREST STUDENTS

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# PREFACE.

1. This Manual has been prepared primarily for the use of the students of the Imperial Forest College, Dehra Dun. In the absence of a suitable botanical text-book a great deal of the time of the instructors and students at the Forest College has hitherto been spent in dictating and copying lecture notes, respectively. The publication of the present Manual, which contains the back-bone, as it were, of the College course of botanical lectures, will enable the instructor to profitably employ much of the time formerly wasted on dictation in repeating parts of the course, in further explaining and illustrating points which are found to give difficulty, and in frequently examining and explaining the characteristics of living plants in the field and in class. Although some plants have been mentioned as examples in the Manual, the number of these is necessarily very limited. It must, however, be remembered that much may be learnt from any individual plant and that the constant illustration of the facts mentioned in the lectures by a reference to living plants is essential if the teaching is to be made interesting and of any practical value, and if it is to have any result other than the committal to memory of a mass of imperfectly understood facts to be reproduced at an examination and then forgotten.

2. The object of the present Manual is to give a general introduction to the science of Botany in accordance with modern knowledge, in so far as this is possible in the limited time available for botanical instruction at the Forest College, particular attention being paid to those points which at present seem to be of special importance for the Forest Officer in India.

3. I have throughout endeavoured to keep in view the needs of the practical Forest Officer,

He should for example possess a good knowledge of the characters most commonly employed in plant descriptions and thus be able to identify plants from their written descriptions and to use a *Flora* with advantage. He should also have an eye for those characters of bark, habit, etc., which enable one to recognise on sight different species in the forest at different times of year.

Such characters are dealt with in *Part I* of the Manual. Those for whom this book is primarily intended have very little time for microscopic work both during their course of training and thereafter. Anatomy therefore is very briefly dealt with in *Part II* and only so far as has been considered necessary for a fairly clear idea of the main facts of Physiology and Pathology as given in *Parts III* and *V*.

4. In accordance with the instructions which were received regarding the preparation of this Manual systematic botany is treated very shortly in *Part IV*. An attempt has there been made to explain the principles of classification, and while avoiding unnecessary detail to give a fair idea of the chief characters and general appearance of the plants contained in the main divisions of the Vegetable Kingdom, as until a student is able to place any plant, according to the aggregate of its characters, into at all events its main group with fair accuracy he cannot be considered competent to use a special *Flora* which only deals in detail with one or more minor groups. The detailed classification of Dicotyledons and Monocotyledons has not been dealt with but the students at the Forest College are required to fully utilise every opportunity they may have of collecting, examining and endeavouring to classify the plants met with on their tours—a task in which they are assisted by Kanjilal's most useful *Forest Flora* of the School Circle which contains full descriptions of most of the important forest species likely to be found, and also by a short course of lectures delivered during the students' tours, giving the characters of the most important cohorts and natural orders of Angiosperms together with the names of the chief plants of

economic importance which they contain. If a future edition of this Manual is called for it will probably be then advisable to add a section dealing with this part of the subject.

5. It is to be hoped that in a few years' time our knowledge of injurious fungi will be sufficient for the compilation of a fully illustrated hand-book describing the most important forest fungi and paying particular attention to characters which can be recognised in the forests. For the present, however, the correct identification of any particular fungus depends on skilled microscopic work and must be left to the expert. The paragraphs of this book which deal with fungi may therefore be considered unnecessarily detailed for students who have little opportunity for working with the microscope. The facts regarding fungi given in *Parts IV* and *V* and the plates illustrating the same, however, merely aim at giving an idea of the general appearance of some typical fungi (the majority of which also the student will have opportunities of seeing and becoming familiar with on his tours), of their life history and injurious action on the plants attacked and also of the microscopic characters on which their classification depends, with the object of helping the student to recognise in the forest the presence of an unknown injurious fungus, to select specimens of the same necessary for its identification by the expert and to form some idea as to the best remedial and protective measures to be taken pending the identification of the pest.

6. The question of Plant Diseases has perhaps been treated on rather broader lines than is usual in an elementary text-book. The principle that a plant's welfare depends on the balance struck between the effects of a number of injurious and favourable factors and that a disease is rarely due to a single factor frequently appears to be insufficiently appreciated, while, until we know more about the normal physiology and life history of our important forest species and about the relations which exist between them and other organisms, plants as well as animals, very little real progress

in the investigation and prevention of the diseases of our valuable forest plants and in our efforts to favour the reproduction of the same appears possible. An attempt has been made to emphasize this point of view in *Parts V* and *VI* of the Manual.

7. While endeavouring in all cases to avoid didactic assertions on points which have not yet been sufficiently proved, I have not hesitated to indicate the possible bearing of well-established botanical facts on Indian forest phenomena with the object of stimulating further observation and research, and in this respect it is hoped that the book may possibly be of some use to others besides those for whom it is primarily intended.

With reference to the plants which have been quoted as examples of the various points considered, I have as a rule selected those which the College students will frequently meet with on their tours, but, with the object of making the book more interesting to Forest Officers generally, I have also included a few well-known species which are not found wild in the neighbourhood of Dehra Dun. In such cases, however, the species in question are usually available for reference in the College Herbarium or Museum.

8. As regards the illustrations, in the time available for the preparation of this Manual only a limited number of plates could be prepared and those have been selected which at present seem most likely to be useful. Thus no drawings of the minute structure of plants for example were prepared, there being a good series of anatomical wall-plates available for instruction purposes in the Forest College.

9. My special thanks are due to Mr. S. Eardley Wilmot, Inspector General of Forests to the Government of India, who very kindly entrusted me with the present work ; to Dr. E. J. Butler, Imperial Mycologist of the Pusa Agricultural Research Institute, who has most generously allowed me to use his original work and drawings for the purpose of this book and to whose help the value of the portions dealing with fungi is entirely due ; to Mr. H. H. Haines of the Imperial

Forest Service who has most kindly read the proofs of *Parts IV, V* and *VI* and given me many valuable suggestions and criticisms most of which I have been able to give effect to, and to Captain Gage, Director of the Botanical Survey of India, for his kind help and advice.

10. During the preparation of this book, covering as it does the main sub-divisions of the whole science of botany, the number of books referred to has necessarily been large and only those to which I am most indebted can be mentioned here. These are :—

(1) The various works of the late Professor H. Marshall Ward, for whose inspiring teaching and encouragement also the writer takes this opportunity of expressing his deep sense of gratitude.

(2) Asa Gray's *Botanical Text-Book*, Volume I.

(3) Dr. E. Strasburger's *Text-Book of Botany.*

(4) *A Students' Text-Book of Botany*, by S. H. Vines.

(5) Sachs' *Lectures on the Physiology of Plants.*

(6) *Physiology of Plants*, by Dr. W. Pfeffer.

(7) *Species and Varieties, their origin by Mutation*, by H. de Vries.

(8) *Diseases of Trees*, by R. Hartig, Eng. Trans., edited by H. Marshall Ward.

(9) *Plant Geography*, by Dr. A. F. W. Schimper.

(10) Brandis' *Flora of North-West and Central India.*

(11) Brandis' *Indian Trees.*

(12) Gamble's *Manual of Indian Timbers.*

(13) *Indian Forester.*

(14) Mr. P. H. Clutterbuck's *Working Plan for the Forests of Jaunsar-Bawar.*

11. Finally it must be noted that all the figures for *Plates I* to *IX, XI* to *XIII* and *XX* inclusive, with the only exception of the diagrams included in *Plates II* and *IX* have been drawn from nature by my wife, to whose work therefore this book owes much of any interest or value it may possess.

R. S. HOLE.

*April 1908.*

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# INTRODUCTION.

1. All living beings are said to belong either to the Animal or Vegetable Kingdom, in other words they are classed, respectively, as Animals or Plants. Biology is a term applied to the study of all living beings, *i.e.* of both animals and plants. The two biological sciences are Zoology and Botany, the former embracing the study of animals, the latter that of plants. **Two Biological Sciences.**

2. So long as we confine our attention to those highly organised forms of life which have an elaborate and complicated structure we find no difficulty in distinguishing the members of the two natural kingdoms. Hence, in early times, when the total number of plants and animals known to scientists was comparatively small while those which were known belonged to the higher forms, a definite line of distinction could be easily drawn between them. With the progress of time knowledge has gradually extended, and with the help of the microscope we have gradually passed from a consideration of the large and obvious to a study of the minute and formerly invisible things of life, and we are now aware of the existence of a number of simple forms of life to which the ordinarily accepted notions of what constitutes an animal, or a plant, fail to apply and which, in consequence, we cannot classify as either. The study of such forms which stand at the bottom of the scale drives us to the conclusion that no definite boundary line can be drawn between the Animal and Vegetable Kingdoms, and it should be borne in mind that the substance which constitutes the basis of life, *viz.* protoplasm, is essentially the same in both animals and plants. With the exception of such simple forms, however, there is generally a great difference between the members of the two kingdoms, and it is obviously convenient for the purpose of study to keep them separate. Animals, then, as compared with plants, usually have more independence of action, while perhaps the most characteristic distinction of the majority of plants consists in the fact that they possess a green colouring matter called *chlorophyll* (a word which means *leaf-green*), by means of which they are **Plants and Animals.**

able to manufacture the food materials necessary for the maintenance of life from the carbon dioxide of the air and water. Animals, being unable to do this, are obliged to maintain themselves by consuming the food manufactured by plants, and if plants were exterminated all life on the earth would cease. Thus plants are often called the great food-producers and animals the great food-consumers. At the same time it must be noted that a large group of plants known as the *Fungi* are exceptional in this respect, for they possess no chlorophyll and like animals depend on green plants for their food.

**Sub-divisions of Botany.** 3. Botany may be sub-divided into the following divisions :—

I. *Vegetable Morphology.*
II. ,, *Anatomy.*
III. ,, *Physiology.*
IV. *Classification* or *Systematic Botany.*
V. *Vegetable Pathology.*
VI. *Geographical Botany.*

The study of the economic uses of plants and of their products is also sometimes treated as a separate branch which is then termed *Economic Botany.*

*Vegetable Morphology* comprises the study of the form of plant bodies and of the several parts of such bodies as visible to the naked eye.

*Vegetable Anatomy* comprises the study of the minute structure of plant bodies as seen by the aid of the microscope.

*Vegetable Physiology* comprises the study of the plant as a living being. Just as morphology regards each plant body, or part of such body, as a *fact*, as something which exists and possesses a certain shape and structure, so Physiology regards it as a *factor*, as something which is capable of action and of performing definite work. While morphology is content with the knowledge of the existence of certain plant structures, Physiology asks what function these structures fulfil and how they do it. Regarded from a purely morphological stand-point, the various parts of a plant body are called *members*. When such parts are regarded as performing some particular kind of work, *i.e.* from the physiological point of view, they are termed *organs*. The greater the number of organs, each being adapted to the performance of one or more functions, possessed by a plant, the more highly organised is the plant said to be.

Although *Part III* of this book is devoted to Physiology, a

few physiological details have also been mentioned, here and there, in the other parts where this has been thought advisable.

*Classification* aims at arranging all plants in groups according to their resemblances, with the object of facilitating the identification of plants and of enabling anyone to rapidly acquire a knowledge of the plants of any particular region and of their correct names, as universally recognised by botanists.

*Vegetable Pathology* includes the study of plant diseases, wounds and injuries.

*Geographical Botany* considers the distribution of plants over the earth and its causes.

**Principal Plant Organs and their Functions.**

4. If we take a seedling of any of our common forest trees we can at once distinguish :—

(*a*) The *Root* which goes downwards and firmly anchors the plant in the substratum on which it is growing.

(*b*) The *Shoot* which goes upwards in a direction diametrically opposite to that of the root and which consists of an axis, or stem, bearing green leaves.

It will help us to understand the various forms assumed by these two sets of organs and their behaviour under different circumstances if we realise, at the outset, that the root absorbs from the substratum in which it is growing water with mineral substances in solution, which, however, are as yet useless to the plant as food and which may be therefore called raw food materials. This water ascends the stem and passes into the green leaves. The protoplasm in these leaves, by the aid of the green chlorophyll and when it is supplied with water by the roots and has air and light in contact with it, is able to build up a carbohydrate, which usually first becomes visible in the form of starch, from the carbon dioxide of the air. This starch contains the energy by means of which the plant is able to live, grow and perform its vital functions—is able not only to feed and keep alive its protoplasm, but also to actually manufacture additional living protoplasm from the inorganic substances brought up by the roots and to carry out other work. The root must thus grow and spread in the dark and moist substratum, while the shoot must come forth into the sunlight and air in order to obtain its supplies of carbon dioxide and to expose its chlorophyll to the rays of sunlight.

The shoot also eventually gives rise, first, to flowers and then, to fruits, the latter containing the seeds which will once

more develop into seedlings and new plants. All plant organs may thus be primarily subdivided into :—

(1) *Vegetative Organs* which enable the plant to exist and maintain itself alive, such as the root, stem and leaves.

(2) *Reproductive Organs* the function of which is to produce new plants, such as flowers.

The root may be distinguished from the shoot by the fact that the former never directly gives rise to leaves, or true reproductive organs.

Selection of Types for Description.

5. Finally, it is necessary to point out that the forms of plants and of their members are almost infinitely various and that, probably, no two members of even one and the same plant are ever exactly alike, although the differences between them are frequently extremely minute. Hence it is obviously impossible to separately define every form which exists. Generally speaking, therefore, morphology aims at the selection of broad types for description, which can be easily distinguished from one another and each of which may be taken as fairly representing the most important characters of a large number of subordinate forms between which the differences are very slight and difficult to distinguish. At the same time, it must be noted that these typical forms are generally connected by intermediate forms, through which one type passes over by almost insensible gradations into another, and that, therefore, although the descriptions of the types apply to a large proportion of all existing forms, there are always some forms for which it is not easy to decide which typical description is most suitable. At the same time this is no practical disadvantage, for forms which are precisely intermediate, may, with equal justice, be referred to either of the two types between which they stand, while all others are referred to the types which they resemble most closely.

# PART I.—MORPHOLOGY.

## Chapter I.—THE ROOT.

6. The first root developed by a seedling is called the *primary root.* All other roots whether developed from the primary root, or from other parts of the plant, are called *secondary.* The root, like the shoot, is capable of branching and rebranching, the new roots being normally developed in longitudinal rows, laterally, on the parent root, in such a way that the youngest are always nearest the growing-apex of the mother-root, *i.e.* they are developed in *acropetal* succession and a line, following the course of development of the lateral roots, passes from the oldest ones at the base of the parent-root to the youngest ones at its apex. **Primary, Secondary and Adventitious Roots.**

The young roots are developed from the inner tissues of the parent-root and as they grow they break through the outer tissues. This can be well seen in the long roots which hang from the branches of the Banyan (*Ficus bengalensis*), the young roots pushing through cracks in the outer tissues of the parent roots. The aggregate of roots developed by a plant constitutes its *root-system.* All roots which are not branches of the primary root, or which, being such branches, are not developed in acropetal succession, are said to be *adventitious,* this term being applied to all parts of plants which develop either in abnormal positions, or out of their proper order. Roots, therefore, may first of all be classified according to their mode of origin into:—

(1) Primary.

(2) Secondary $\begin{cases} (a) \text{ Normal.} \\ (b) \text{ Adventitious.} \end{cases}$

Roots which spring from the stem are therefore adventitious, such as are those often seen on the sugarcane as shown in *Plate I, Fig. 4.*

7. If we examine the seedling of one of our common forest trees, say an Oak, we shall find that the primary root elongates and continues to grow vigorously for a considerable period. Such a root is termed a *tap-root* and all the roots developed from it are its *lateral roots,* see *Fig. 1, Plate I.* If the tap-root is injured a **Types of Root-Systems.**

lateral root usually takes its place and continues its growth in the direction of the original tap-root. A root-system with a tap-root has thus a distinct main axis and usually penetrates to a considerable depth in the soil. A strong tap-root is developed by many of our forest trees, *e.g.* Teak (*Tectona grandis*), Sissoo, (*Dalbergia Sissoo*) and Anjan (*Hardwickia binata*). Such a root of Sissoo, or Anjan, may attain a length of six feet in the first year.

In many plants, however, such as grasses and their allies, the first root sent out by the seedling dies off after a short time, or does not develop vigorously, and stronger roots then spring from the base of the stem above the primary root. These, although they often arise above the ground in the air, may ultimately penetrate the soil and branch there, and in many plants the entire root-system consists of such adventitious roots. They may be well seen in the sugarcane. For illustrations, see *Plate I*, *Figs. 3* and *4*.

The question whether a plant develops a strong tap-root, or a superficial root-system, is of great practical importance. Plants with the same type of root-system compete with each other in the same layers of soil for water and raw food materials. A tree with a long tap-root, like the Sissoo, is thus a good nurse to protect tea-bushes from the effects of frost, the roots of these two plants not interfering with each other, while the superficial roots of Toon (*Cedrela Toona*) and other species, which are often planted in avenues near field crops, are injurious to the latter.

The extent of the root-system developed by a plant depends on the amount of green foliage produced by the shoot. The greater the latter, the larger and more vigorous is the former. Plants with leaves floating in water usually have a small total area of leaf surface, while water also is plentiful close at hand, and such plants usually possess a small root-system. If, on the other hand, we collect all the roots of a large forest tree, such as the Sal, and place them end to end they would probably cover a distance of several miles.

**Development of Root precedes that of Shoot.**

8. In the case of many of our forest trees the development of the root to a great extent precedes that of the shoot. The plant, as it were, has to make sure of its foundations below ground before proceeding with the superstructure and the development of the shoot above ground may often be quite insignificant for several years, during the early life of the seedling. *Fig. 1*, *Plate I*, shows the strong well-developed tap-root of a young seedling of

the Ban Oak (*Quercus incana*) and the insignificant young shoot. In some cases no true leaves at all are developed during the first year but only rudimentary leaves, small scaly structures, such as are seen in *Figs. 1* and *2, Plate I*. In many cases the young shoot of the seedling dies back year after year more or less completely, while the development of the root-system steadily progresses, such as frequently happens with Teak and Sal. Eventually, when a vigorous root-system has been developed, a strong shoot is sent up which is capable of ultimately forming a full-sized mature shoot. The advantage of this procedure is often obvious, such as is the case for example with those trees like Sal, Harra (*Terminalia Chebula*), Jamun (*Eugenia Jambolana*), and Mahua (*Bassia latifolia*), which, in the plains of India, come into leaf during the hot dry season from March to May, when the roots are obliged to send up large quantities of water to supply the leaves, and it is therefore necessary that the roots should be in the deep moist subsoil and not in the parched surface soil. In such trees, therefore, a strong deep-going root-system must be formed before a vigorous shoot can be developed.

**Root Suckers.**

9. Although roots never directly give rise to leaves, they are capable, under certain circumstances, of bearing buds which may develop into leafy shoots called *root-suckers*, which are characteristic of many of our forest trees and shrubs, such as Sissoo, Tendu (*Diospyros tomentosa*) and many others. They are often found springing from roots which have been exposed to the light at the sides of a road-cutting, or on the banks of streams, for example.

**Fibrous and Tuberous Roots.**

10. A typical root is usually cylindrical in shape and when fine and thread-like it is termed *fibrous*. Many plants manufacture more food material than is required for immediate consumption, this excess material being stored until it is wanted. The subterranean roots and the lower part of the stem are favourite reservoirs for such food and as they are stuffed with the material they become much swollen and lose their ordinary shape. In some plants, such as the Radish, Turnip, Carrot and Beet, the tap-root is swollen, in others, such as the Dahlia, the secondary roots are stuffed. Such swollen roots are said to be *tuberous*. If the swollen root is broader in the middle and tapers towards both ends, like a spindle, it is said to be *fusiform*, if it is like a turnip, broader than high, it is *napiform*, and if tapering regularly from a broad base to the tip like a carrot, it is *conical*.

Woody Roots.

11. In the case of most trees the old roots become hard and woody as they thicken and then they no longer absorb water and food materials from the soil but merely serve as conducting pipes to pass on to the stem the supplies which have been collected by the younger roots. They also anchor the tree more strongly in the ground, the massive roots resisting the lever-like strains exerted by the heavy trunk with its great crown of foliage, as it sways in the wind. In the case of many Indian trees the roots form woody supports, like buttresses, at the base of the trunk, which are for instance very characteristic of *Bombax malabaricum*, see *Fig. 4, Plate XI.*

Subterranean Aquatic and Ærial Roots.

12. According as roots are developed in the earth, water, or air, they may be called *subterranean*, *aquatic* or *ærial*. The ærial roots of the Banyan on reaching the soil, branch and develop a vigorous root-system therein, while the ærial portions become woody and support the horizontal branches like columns. In *Rubus lasiocarpus*, the ærial roots produced at the tips of the long curved branches give rise to young plants, which become independent and are separated from the parent by the decay of the connecting branches.

Other ærial roots serve as attachment organs and enable climbing stems to cling firmly to their substratum; these are found in the Ivy, *Ficus scandens*, and many others. These roots are also in some cases able to absorb moisture and food materials, provided that such are available. Thus some climbing stems are able to exist after they have been cut and their connection with the subterranean root system severed.

Sometimes the ærial roots originating on the stem grow obliquely downwards into the ground and form remarkable stilt-like supports which may be seen in Screw-Pines (*Pandanus*), Mangroves (*Rhizophora*), and, in miniature, sometimes in the Maize (*Zea Mays*). Some ærial roots possess the exceptional power of being able to absorb moisture from the air by means of a spongy outer sheath of tissue called the *velamen*, found in many orchids. In a few cases also the ærial roots are green in colour and possess chlorophyll.

## Chapter II.—THE STEM.

13. As has been noted above, the stem of a plant bears the structures which we call leaves. If we examine an ordinary stem we find that the leaves are situated at certain definite positions on it, which are separated by a more or less considerable length of stem which bears no leaves. The places where the leaves are borne are called the *nodes*, the piece of stem lying between two successive nodes is called an *internode*. The nodes are often swollen and are sometimes marked by a distinct line or joint, as in *Gnetum*. The youngest leaves are found to be nearest the growing apex of the stem, *i.e.* they are developed in acropetal succession. If only two leaves occur on one node they are on opposite sides of the stem and are said to be *opposite*, if there is only one leaf at each node, the leaves are said to be *alternate*, or *scattered*. If more than two leaves occur at a node, they are situated at equal distances apart and are then said to be in *whorls* (or in *verticils*) or *whorled* (or *verticillate*). If at each node there are two leaves which are nearly, but not quite, opposite, they are said to be *sub-opposite*. When more than two leaves occur at a node which are nearly, but not quite, at the same level, they are said to be in *false* whorls (or verticils). In practical descriptive botany, however, the difference between true and false whorls (or verticils) is often not insisted on, both being merely called whorls (or verticils). When pairs of opposite leaves are arranged on the stem in such a way that the longitudinal axis of each pair is at right angles to the axis of the pair above and below it, the leaves are said to be *decussate*, and are then in four vertical ranks. When leaves are arranged in two vertical ranks they are *distichous*, or *bifarious*. When two or more leaves are inserted very close together so that they appear to be in tufts, the leaves are said to be *fascicled*, or in *fascicles*, as in the Deodar. The upper angle between a leaf and the stem is called the *axil*. On the stem, in addition to leaves, we find the structures which we call *buds* and which are capable of growing out into new stems, or branches. These buds are normally found in the axils of the leaves when they are called *axillary*, or at the apex of the stem when they are said to be *terminal*. The leaf, in the axil of which a bud appears, is called the *subtending leaf*, while the bud, having a leaf close below it, is said to be subtended by the leaf.

**Nodes, Internodes, Position of Leaves and Buds.**

This fact that buds, and the branches which develop from them, as a rule occupy a definite position as regards the leaves is of great importance, and we are thus helped in doubtful cases to arrive at a decision as to whether a certain member is to be regarded as of the nature of a branch or of a leaf. Whatever first arises in the axil of a leaf may usually be regarded as a branch, and what subtends a branch as a leaf.

**Various Kinds of Stems.**

14. A stem which is soft and more or less succulent is said to be *herbaceous*, if firm, and more or less tough and hard, it is said to be *woody*.

In some plants there is very little, if any, stem and they are said to be stemless, or *acaulescent*, *e.g.* *Phœnix acaulis*. In others there are several stems of equal vigour ; such stems, occurring in tufts, are said to be *caespitose*, as in many Bamboos.

Stems are :—

*erect*, when ascending perpendicularly,
*ascending*, when rising obliquely,
*decumbent*, when erect, but with the basal portion horizontal, or nearly so,
*reclining*, when the basal portion is more or less erect and the upper portion curved downwards with the apex trailing on the ground,
*procumbent*, or *prostrate*, when lying on the ground,
*repent*, or *creeping*, when prostrate and also rooting as they grow,
*scandent*, when climbing,
*twining*, when they climb by spirally coiling around a support. Twiners may ascend in two directions, *i.e.* they may ascend from left to right, as viewed from outside the coil, in which case they are said to be *dextrorse* and to move in an *anti*—or *counter-clockwise* direction, or they may ascend from right to left, when they are said to be *sinistrorse* and to move in a *clockwise* direction, see *Fig. 1*, *Plate II*.

Stems may also climb by means of special organs called *tendrils*. These are slender, thread-like bodies, simple or branched, which firmly attach themselves to a support by coiling around it, or by adhering to it, and thus hold the stem securely. Others climb by means of hooks and spines, *e.g.* *Calamus tenuis*.

The stems of some plants, although not distinctly climbing, are wide-spreading and may often be found resting on, and more or less entangled with, the stems and branches of other

plants. They are, as it were, weak, or imperfect, climbers, and are usually described as *rambling*, or *straggling*, *e.g.* *Quisqualis indica* and *Deeringia celosioides*.

A large climber with a woody stem is called a *liane*, *e.g.* *Bauhinia Vahlü*.

A stem rising directly from the ground, bearing flowers, but no green leaves, is called a *scape*, *e.g.* *Orobanche indica*.

The peculiar jointed stems of grasses and bamboos which are hollow between the joints are called *culms*.

The unbranched columnar stem of palms and Tree Ferns is termed a *caudex*.

An ærial or subterranean branch, rooting and giving off shoots which become independent plants, by the decay of the branch connecting them with the parent stem, are called *stolons*. The Potato has subterranean stolons, while the rooting branches of *Rubus lasiocarpus* are ærial stolons.

A *runner* is a slender stolon with long internodes, well seen in the Strawberry. A plant which produces a number of stolons, or runners, is said to be *sarmentose*.

A *rhizome* is a stem of root-like appearance prostrate on, or buried under, the ground, giving off slender roots usually at the nodes and producing erect ærial shoots, or leaves, progressively from the growing apex, as found in many Grasses, Bamboos and the common Bracken Fern, *Pteris aquilina*.

Stolons, runners, and rhizomes, are sometimes very like roots, but they may always be distinguished from roots by the fact that they directly give rise to leaves in the axils of which buds appear, although such leaves are usually minute and scale-like.

A *bulb* is a short shoot with a flattened or conical stem, provided with thick, fleshy, scale-like leaves and from the base of which roots are developed, *e.g.* the Onion.

A *corm* is like a solid bulb, the main portion of the corm consisting of the thickened stem which is naked, or with a few inconspicuous, scaly, investing leaves.

A *tuber* is a short thickened shoot, or part of a shoot, bearing inconspicuous scaly leaves, with buds in their axils. In the Potato, tubers are formed at the ends of stolons, the so-called "eyes" being the axillary buds. A tuber can be distinguished from a tuberous root by the fact that it bears scaly leaves, in the axils of which the buds arise. Small bulbs, corms and tubers sometimes appear on ærial stems in the leaf-axils and they are then called *bulbils*, which are found in many species of *Dioscorea*. They are capable of developing roots and producing independent plants.

A *cladode* is a stem coloured green, with, or without, inconspicuous scale leaves, which more or less resembles a leaf and performs the functions of a leaf, *e.g.* the stem of the prickly pear, *Opuntia Dillenii.*

Branching. 15. Branching, *i.e.* the production of new stems from the parent stem, takes place in two principal ways termed, respectively, *dichotomous* and *lateral* branching. In the first the growing point of the parent stem divides into two ; two branches of equal vigour are thus formed, as in a two-pronged fork, and there is no continuous main axis. This method of branching is very rare.

In lateral branching the growing point of the parent stem does not divide and new stems are developed laterally from the parent. There are two principal kinds of lateral branching, the *monopodial* and *cymose.* In the former there is a distinct and simple main axis, formed by the elongation of the parent stem. Such a main axis is termed a *monopodium.* Such a system of branching is well seen in a Pine tree in which the leader has uninterruptedly developed from the terminal bud.

In cymose branching there is no simple main axis formed by the elongation of the parent stem and the lateral branches grow faster, or for a longer period, than the parent. Of this form of branching there are two types, the *sympodial* and *falsely di-* or *tri-chotomous.* In sympodial branching there is a main axis but this, instead of being a simple axis consisting of the parent stem, is built up of the basal portions of a number of lateral branches. On each segment of such an axis, one lateral branch develops more vigorously than any other, *i.e.* there is one leader. The axis so formed is termed a *sympodium*, or false axis, and is at first crooked but frequently straightens subsequently, see *Fig. 2*, *Plate II.* This may often be seen on the twigs of trees the terminal buds of which have died, or not developed vigorously, and the leaders have been formed by the axillary and therefore lateral buds. In falsely dichotomous branching, such as occurs for instance in *Rhamnus virgatus*, the branches are forked and at first sight there appears to have been a division of the growing point of the parent stem. On closer inspection it appears that in this plant the growing point really terminates in a spine and that there is no dichotomy. In some plants the terminal bud becomes a flower, and in others it dies, or does not develop. A system of branches each one of which forks in this way and produces a pair of lateral branches of equal vigour

is called a *false-dichotomy*, or a *dichasium*. If three lateral branches develop with equal vigour the branching is *falsely trichotomous*. In botanical descriptions, however, no distinction is as a rule made between falsely and truly di- or tri-chotomous, the branching being merely described as *dichotomous*, or *trichotomous*, respectively. We are accustomed to associate the word branching principally with the stem of plants, but it must be remembered that precisely similar branching may be exhibited by the root, or leaf, or other members.

Branches as a rule arise normally in acropetal succession and in the leaf axils, *i.e.* they are axillary. Those which originate otherwise are adventitious, *i.e.* they are developed out of their proper order, or in altogether exceptional positions.

As branches are usually axillary their arrangement follows that of the leaves, and like leaves they may therefore be opposite, sub-opposite, alternate, whorled and so on. In many plants while some branches remain stunted and short, others grow rapidly, and there are in consequence *elongated* and *dwarf* shoots. These occur, for instance, in *Randia dumetorum* and *Pyrus Pashia*, see *Fig. 3, Plate II.* Such dwarf shoots in many cases develop into spines and at first sight it is not always easy to decide whether such spines are to be regarded as altered (*metamorphosed*) leaves, or stems, but as a rule they are found in the axils of leaves, or they themselves directly give rise to leaves, thus indicating that they are stems, or rather branches. The spines of the Bel, *Aegle Marmelos*, of *Flacourtia Cataphracta* and others may frequently be seen bearing leaves, see *Figs. 1* and *2, Plate III.*

In the Pine we find that there are two kinds of leaves. The first are small and scale-like, in the axils of which small dwarf shoots with brown scales at the base and terminating in two or more long green leaves, or needles, are borne. On the dwarf-shoots of the Deodar the internodes remain so short that the leaves (needles) appear to be in tufts, or fascicles.

The tendrils of *Gouania leptostachya* do not at first sight appear to be branches but, as in the case of the spines of the Bel, the true nature of these organs is indicated by the fact that they originate in the leaf-axils and bear leaves, just as do normal branches, see *Fig. 3, Plate III.*

In some plants the stem remains simple and does not branch, *e.g.*, in the majority of Palms. In a plant in which the stem repeatedly branches, the branches thus produced again branching and so on, such as is the case with most of our

forest trees, the smallest branches which have been produced most recently are called *twigs*, the smaller branches *branchlets*, and the larger ones *branches*.

Shape of Stem.

16. The shape of the stem and branches varies considerably in different plants and often helps the Forester to distinguish his trees in the forest. Many trees have large buttresses at the base of the trunk, *e.g. Bombax malabaricum*, see *Fig. 4, Plate XI*. In *Ougeinia dalbergioides* the stem is usually short and almost always crooked. In *Acacia leucophlœa* it is almost always crooked and knotty (*gnarled*). In the Hornbeam, *Carpinus viminea*, it is distinctly *fluted*, *i.e.* with broad, shallow, curved grooves.

In many plants the stem is cylindrical, *i.e. terete*, in others the stem has 3, 5, or more distinct ridges or angles. Sometimes, in addition to being angled, the stem is more or less deeply grooved, or hollowed out between the angles, and it is said to be *channelled*. If the stem is marked with more or less parallel furrows it is *sulcate*, if the furrows are very minute and look like mere lines the stem is said to be *striate*. The stems of lianes are frequently irregular in shape and are flattened or deeply grooved.

Such peculiarities, although as a rule not noticeable on the old stems and branches of trees and shrubs, are often very characteristic of branchlets and twigs. The branchlets of *Flemingia stricta*, for instance, are 3-angled (*triquetrous*), those of *Coriaria nepalensis* are quadrangular, those of Teak are channelled, and those of *Flemingia congesta* are sulcate.

Stem Structure, Bark.

17. If now we cut through a stem of one of our common forest trees, say the Teak, and examine the cut surface, we find the greater portion of the interior of the stem to be solid and hard, consisting of the so-called wood, which is enveloped in a comparatively thin external coat of softer substance of a different colour, which can be detached from, and stripped off, the solid woody cylinder which it covers. This outer coat is the so-called *cortex*, or *bark*, of the Forester; its characteristics vary greatly in different species and the Forester finds them very valuable for the identification of trees in the forest. In some plants, *e.g.* Palms and Bamboos, there is no true bark. The first characteristic of the bark to be noted is its thickness; on the stems of young plants and the twigs of old plants it is very thin. On the old stems of trees and shrubs its thickness varies greatly in different species. Thus in *Ougeinia dalbergioides* it

is only about one-sixth of an inch thick, whereas in Sal its thickness is from 1 to 2 inches.

There is usually a considerable difference both in colour and texture between the outer and inner layers of bark, thus in *Phyllanthus Emblica* the outer bark is pale grey and the inner substance is red ; in most trees and shrubs also the inner substance is distinctly moist while the outer tissue is dead and dry.

On the stems of young plants and twigs of old trees the exterior of the bark is usually smooth, but on the old stems of trees and shrubs the degree of roughness varies greatly in different species. In *Sterculia urens*, for example, it is very smooth and affords a marked contrast to the rough bark of say an old Sal tree. Smooth stems may, or may not, be shining : in *Anogeissus latifolia* the smooth stem is not shining, while in the Birch it is.

The colour of the external bark is not only different in different species but varies on different parts of one and the same plant. Thus the twigs and branches of *Carissa spinarum* are bright green, but the old stems are grey, or yellowish.

The twigs and branches of *Berberis aristata* are dark red, of *Rubus lasiocarpus* purple and of *Salix daphnoides* dark green, or almost black. The colour of the bark on the stems of trees and shrubs is very important for identification and the following may be noted as examples :—

In *Betula utilis* it is almost white.
In *Albizzia procera* it is greenish.
In *Boswellia serrata* it is yellowish.
In *Stephegyne parvifolia* it is bluish-grey.
In *Anogeissus latifolia* it is pale grey.
In *Terminalia Arjuna* it is pale pinkish-grey.
In *Diospyros tomentosa* it is almost black.
In *Sterculia urens* it is sometimes dark red.

The texture of the bark also varies greatly in different species : in *Betula utilis* it is papery, in *Erythrina suberosa* corky, while in Teak and *Cupressus torulosa* it is fibrous, *i.e.* it breaks up into thin long threads.

The bark of old branches and stems may, or may not, have fissures, or cracks, of various kinds. The stem of *Anogeissus latifolia* is smooth without characteristic fissures. When there are fissures they may be shallow as in Teak, or deep as in *Pinus longifolia*. The way in which such fissures run, whether vertically or horizontally, and the way in which they join, or cross, one another are also characteristic. In *Buchanania*

*latifolia* these fissures cross at right angles cutting the surface of the bark into small squares and producing a tessellated appearance ; in other cases strips and plates, or scales, of various shapes and sizes are produced.

As the stem of a tree or shrub increases in size the outer layers of bark are cast off and the way in which this is done is often characteristic. In the Birch, the bark peels off, *i.e. exfoliates*, in rolls, in the Khair (*Acacia Catechu*) in long narrow strips which remain for some time on the trees giving a ragged appearance, and in *Gmelina arborea* in large, irregularly shaped, scales, thus exposing patches of pale yellowish surface below which contrast strongly with the grey external bark.

**Leaf-Scars and Lenticels.**

18. The bark on young stems, on branchlets and on twigs often exhibits peculiar and characteristic marks, the principal of which are the so-called *leaf-scars* which mark the spots from which the leaves have fallen, and the *lenticels.* The leaf-scars of course follow the arrangement of the leaves and in deciduous species we can at once see from the position of these scars whether the leaves are opposite, alternate, whorled and so on. Their size and shape vary greatly in different species. A reference to *Figs. 1* and *2*, *Plate XI*, will indicate how we may readily distinguish two trees (*Odina Wodier* and *Hymenodictyon excelsum*), which, when bare of leaves, are somewhat alike in the forest, by an inspection of their twigs and principally by the shape and arrangement of their leaf-scars. In some cases the entire leaf is not shed and the bases of the leaves persist and give the stem a ragged appearance, as in species of *Phœnix.*

Lenticels are interruptions in the outer coat of bark which allow air to penetrate to the internal tissues and they usually appear as raised corky spots, or lines, of varying shape and size. In the Birch, for instance, they are horizontal lines, being very large and conspicuous, while in *Pyrus Pashia* they are small spots. They are often of a paler colour than the surrounding bark and are thus made conspicuous.

**Internal structure.**

19. If now we look at the cut surface of that portion of our teak stem which lies inside the bark we find certain peculiarities which require notice.

**Pith.**

In the centre there is a small area of soft tissue called the *pith* which, in young stems, branches and twigs, is often large and conspicuous. The size and shape of the pith varies in different species. As a rule it is small, but in Teak it is relatively large and conspicuous. In the Walnut and *Prinsepia utilis* it is divided into characteristic large chambers. In cross

section it is quadrangular in Teak, nearly circular in *Corylus Colurna*, the shape of a cross in *Bauhinia Vahlii*, usually oblong in Birches and pentagonal in Oaks.

**Heart- and Sap-Wood.** The remainder of the stem lying between the pith and the bark is occupied by the wood proper and, unless our stem is too young, we shall find that the central portion of this woody cylinder is dark-coloured and is surrounded by a belt of paler wood. The former is the *heart-wood* or *duramen* and the latter the *sap-wood* or *alburnum*. In some trees, *e.g.* the Silver Fir, there is no heart-wood, but when this is present its colour and size in comparison with those of the sap-wood are important characters. In Teak the heart-wood, when fresh, is dark golden yellow and the sap-wood is white.

**Annual Rings.** In the wood, arranged around the pith, we find numerous lines which divide the wood into concentric layers; the latter are the *annual rings*, so-called because each of them usually represents the amount of wood formed in one year and hence by counting these rings the age of the stem may be calculated. These rings are due to a difference in the density of adjacent concentric layers of wood, the wood formed on the outer side of each ring being denser than that on the inner side of the next ring which adjoins it. In several species no annual rings are found, *e.g.* the Mango; in others there are so-called *false rings*, *i.e.* bands of tissue which do not pass uninterruptedly around the stem and which often run into one another. These may be seen in *Pongamia glabra* and *Quercus semecarpifolia*.

**Medullary Rays.** Through the wood, passing from the centre outwards, towards the circumference of the stem, are radiating lines called the *medullary rays*. The presence or absence, width and other characters, of these rays are important points in the identification of different woods. If we split a piece of the Teak stem radially we find the medullary rays appearing on the surface of the radial section as shining plates, giving an ornamental appearance to the wood and constituting the so-called *silver-grain*. Looking again at the cross section of our stem we find a number of minute pores which are larger and more numerous in the inner part of each annual ring than in the outer part. The size of these pores and the way in which they are distributed throughout the wood are important characters for the identification of trees from their wood. **Pores.**

The hardness and weight of wood are also well-known characters for distinguishing trees. With Teak, for example, we may compare the much softer, lighter wood of *Erythrina*

*suberosa* and the considerably harder and heavier wood of *Xylia dolabriformis.*

Finally the characteristic scent of the Teak wood should be noted and compared, for example, with that of the wood of Sandal, Toon and Deodar.

The stem of our example, the Teak, of which we have now shortly considered the most important and obvious characteristics, may be taken as typical of the stems of the great majority of the trees and shrubs of our forests, and some of the modifications of this typical structure found in different species have also been noted. It must be mentioned, however, that in some species there is a remarkable departure from the type in that there are narrow, more or less concentric, bands of soft, bark-like tissue, alternating with bands of woody tissue throughout the stem. These are found for example in *Dalbergia paniculata* and *Cocculus laurifolius.* A similar structure is often seen in the woody stems of climbers, *e.g.* in *Bauhinia Vahlii*, in which the layers of porous wood alternate with soft, red, bark-like tissue.

If now we look at a section of a Deodar stem we find, as before, a pith, distinct bark, and wood showing both heart- and sap-wood, while in the wood are annual rings and medullary rays. There is, however, a great difference from the Teak wood in that here we have no pores, the annual rings being marked by the darker colour of the denser wood on the outside of each ring contrasting with the lighter colour of that on the inside of the rings. This absence of pores is characteristic of the wood of all the trees and shrubs commonly known as Conifers. In some conifers, although there are no

Resin-Canals.

pores, there are what are called *resin-canals* or *-ducts*, which on a transverse section may at first be mistaken for true pores. They may be distinguished by their irregular outline and they are usually sparsely distributed through the wood. They are well seen on a transverse section of *Pinus longifolia.*

If now we look at the section of a Palm, *e.g. Borassus flabellifer*, we find that there is no distinct bark which can be stripped off and there are no medullary rays or annual rings. Scattered throughout the soft tissue of the stem, we find numerous rounded, hard, black areas, in the interior of some

Vascular Bundles.

of which is a large pore. These are the so-called *vascular bundles.* Those situated towards the exterior of the stem are usually without pores and are closer together than those towards the centre, and the outer portion of the stem is consequently much harder and denser than the interior. The section

of the stem of a Bamboo is somewhat similar, but the vascular bundles are not so conspicuous and the interior of the stem is usually hollow, except at the joints. In the stem of a Tree Fern also there is no distinct bark, and we find an exterior coat consisting of the bases of fallen leaves and adventitious roots and a central portion of soft tissue, which often disappears and leaves a hollow in old stems, while between these lies a ring of harder woody tissue which contains characteristic vascular bundles, usually crescent-shaped and with a dark-coloured border.

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## CHAPTER III.—THE LEAF.

20. If we look at the foliage leaf of say the Teak tree we at once recognise that it consists of two principal parts (1) the expanded apical portion called the blade or *lamina* and (2) the stalk, or *petiole*. In some plants the leaves have no petiole and they are then said to be *sessile*, whereas leaves with a distinct stalk are *petiolate*.

Nerves.

On looking at the lamina we find a framework of firm ribs traversing its surface in all directions, between which the soft green tissue is stretched, much like the cloth over the ribs of an umbrella. The largest and most prominent of these are usually distinguished as *ribs, nerves*, or *veins*, and the smallest as *veinlets*. For the present we may include them all under the general term strands. These strands of firm tissue, if followed up, will be found to extend from the leaf blade through the petiole and stem down to the root, the strands in the leaf being, in fact, branches of similar stouter strands in the stem, which are the so-called vascular bundles. These give the necessary rigidity and strength to the plant enabling the stem to stand erect and the flat leaf-blades to remain extended in the sunlight. These cords of tissue also contain minute pipe-like structures which will be considered in detail later, but through some of which, it may now be noted, water with mineral salts in solution passes from the roots to the green leaf, while others bring back into the stem the food materials manufactured in the leaf by the help of the green chlorophyll under the influence of sunlight, and carry them to those points where they are required. When leaves are cast off, the places where the vascular strands pass into the stem from the leaf are usually distinguishable on the resulting leaf-scars as more or less evident dots, or rounded marks. The number, shape, and arrangement of these marks on the scar are often very characteristic.

Venation.

21. The way in which the strands are arranged in the leaf is important and is called the *venation* of the leaf. Two main classes of leaves are usually distinguished, *viz* :—

(1) *Parallel-veined.*
(2) *Reticulate-* or *net-veined.*

In parallel venation all the strands which can be easily seen

with the naked eye run approximately parallel to one another. They usually run from the base of the leaf to the apex, as in a Grass, or Bamboo. The term, however, is also applied to cases where there is one main strand traversing the leaf-blade from base to apex, called the *midrib*, and from which all other noticeable strands run approximately parallel to each other towards the leaf-margin, as in a Banana leaf. In both cases a few minute, inconspicuous, and generally straight, strands usually connect the main strands and run at right angles to them. These are conspicuous in the leaves of *Arundinaria spathiflora*. In reticulate venation the strands are seen to branch in all directions and thus give rise to an elaborate network, as in a Teak leaf. When there is a distinct midrib from which all the other nerves, directly or indirectly, spring, the nerves which spring from the midrib are called *lateral* nerves and the leaf is said to be *penninerved*, or *pinnately-veined*. In such cases also the midrib is said to be the *primary* nerve, the larger nerves springing from the midrib are called *secondary* nerves, and the smaller nerves springing from the latter the *tertiary* nerves.

In some cases in this type of leaf, the lower pair or two of lateral nerves are much more prominent than the remainder, as in *Cinnamomum Camphora*, see *Fig. 5, Plate IV*. Such cases bring us by insensible gradations to the next type of venation in which there is more than one main rib, or primary nerve, entering the base of the blade and the leaf is then said to be *palminerved*, or *palmately-* or *digitately-veined*. According to the number of the strong basal nerves the leaf is said to be palmately—or digitately—5 nerved, 7 nerved and so on.

Nerves may be straight or more or less curved. Those which are slightly bent in the form of a bow and run in a regular sweeping curve are called *arcuate*, those which are more sharply bent are *arched*. A leaf of *Quercus incana* may be taken as an example of a penninerved leaf with straight secondary nerves, see *Fig. 1, Plate IV*. Such a leaf differs from a typical parallel-veined leaf, such as that of the Banana, in having the secondary veins further apart and the spaces between them filled with distinctly reticulated strands. A leaf of *Acer caesium*, *Fig. 2, Plate IV*, furnishes an example of a palminerved leaf with straight primary nerves. The penninerved leaf of *Cornus macrophylla*, *Fig. 3, Plate IV*, has arcuate secondary nerves. The palminerved leaf of *Smilax parvifolia*, *Fig. 4, Plate IV*, has arcuate primary nerves. By some botanists the term palminerved is restricted to cases

in which the primary nerves are practically straight; when they are curved, the leaf is merely described as having 5, 7, or more, basal nerves. When the secondary nerves are curved each one frequently runs into and joins the next secondary above it, the junction taking place near the leaf margin. A continuous strong nerve, composed of the ends of the secondary nerves, is thus formed close to the leaf margin. This is called a *marginal*, or *intramarginal*, nerve and may be seen in *Ficus bengalensis*, or *Eugenia Jambolana*. Such a nerve prevents the leaf blade from being easily torn. A Banana leaf has no such nerve and is quickly torn into strips by the wind. If this were not so the enormous leaf blade would offer great resistance to the wind and the plant's tissues would be subjected to a dangerous strain. As a rule a midrib divides the leaf blade into two practically equal divisions. When these divisions are unequal the leaf is said to be *oblique*, as is the case in *Ficus Cunia*. When nerves continually fork and divide into two branches of approximately equal size, the venation is called *furcate* and is characteristic of many Ferns, see *Fig. 6, Plate IV*.

**Leaf margin.** 22. The margin of a leaf is said to be *entire* when it is an even line not indented in any way, *serrate* when with sharp teeth directed towards the leaf apex, *bi-serrate* when each main tooth is again serrated, *serrulate* when serrate with very small teeth, *runcinate* when serrate with the teeth directed backwards, *dentate* or *toothed* when the teeth are triangular and directed outwards, *crenate* when with rounded teeth, *repand* when it is a gently undulating line, *sinuate*, or *undulate*, when the undulations are more pronounced. When the margin is fringed with fine and close-set hairs it is *ciliate*, and when it is cut into a number of long narrow segments it is *fimbriate*.

When the incisions are deeper, but do not extend more than half-way to the midrib in the case of a penninerved leaf, or to the base of the blade in the case of a palminerved leaf, the leaf is said to be *lobed* or *cleft*, according as the leaf divisions, or the spaces between them, are broad and rounded or narrow and acute. When the incisions extend still deeper, the leaf is said to be *partite*, or *parted*, and when they reach the midrib or base of the blade, thus dividing the leaf into distinct parts, the leaf is said to be *divided*. In this case the parts so divided off are called *segments* and they cannot be separated from the midrib or petiole without the lamina being torn. When each of these divisions has a separate insertion

of its own, there being no trace of lamina at the place of insertion, and when each of them can be separated from the common leaf-stalk without tearing, just as the whole leaf may be separated from the stem, the leaf is known as a *compound* leaf, in contra-distinction to a *simple* leaf which is not thus divided. The parts of a simple leaf blade are known as segments, or lobes, while each separate division of a compound leaf is called a *leaflet.* The terms given above for the description of a simple leaf, as to its venation, margin and so on, are equally applicable to each leaflet of a compound leaf. Each leaflet may be sessile or provided with a stalk, the latter being called a *petiolule.* The various shapes of the leaf blade are caused by portions of the leaf growing faster than others, and we get first an uneven margin, then a lobed, cleft, parted, and finally a divided, or compound leaf. As in such cases the growth in the direction of the main nerves is usually more vigorous than that of the portions of the blade between them, a pinnately-nerved leaf gives rise to a pinnately-lobed,—cleft,—parted,—divided, or compound leaf, and a palmately-nerved leaf to a palmately,—lobed,—cleft,—parted,—divided, or compound leaf. *Pinnately-* and *palmately-cleft* are synonymous with, and often replaced by, the terms *pinnatifid* and *palmatifid* respectively — Simple and Compound Leaves.

Similarly the terms *pinnately*—and *palmately—divided* are synonymous with the terms *pinnatisect* and *palmatisect.*

23. The following terms are most frequently employed for describing the general shape of the blade of a leaf or leaflet. They are of course applicable to any plane surface and so may be used for other organs besides leaves. As they refer to plane surfaces with an entire margin, in order to describe the general shape of a leaf the margin of which is not entire, it is usual to consider the general shape as defined by an imaginary line passing through the base and apex of the leaf-blade and touching the summits of all the principal teeth, lobes, or segments, of the lamina. — General shape of Leaves.

1. *Acicular;* needle-shaped, very much longer than wide and tapering to a point, such as a Pine leaf.
2. *Linear;* several times longer than wide with almost parallel sides.
3. *Subulate;* awl-shaped, acicular with a broad base.
4. *Lanceolate;* like a spear-head. Several times longer than wide but tapering to both ends, with the greatest width below the centre.

5. *Oblong ;* two or three times as long as broad with almost parallel sides.
6. *Elliptical ;* oblong with a regularly curved outline.
7. *Oval ;* broadly elliptic. The width more than half the length.
8. *Ovate ;* like the outline of an egg with the broader end at the base.
9. *Orbicular ;* circular or nearly so.
10. *Cuneate ;* wedge-shaped. Broad at apex and narrow at base.
11. *Deltoid* or *triangular ;* cuneate with the width at the base.
12. *Spatulate ;* spoon-shaped. Rounded above, long and narrow below.
13. *Reniform ;* kidney-shaped.
14. *Falcate ;* sickle-shaped. Curved like the blade of a sickle, or scythe.

For describing the extremity of the leaf, whether the base or apex, the following terms are most commonly used, 1 to 9 being generally applied to the apex and 10 to 13 to the base.

1. *Acuminate ;* with a long tapering point.
2. *Acute :* ending in an acute angle, the point not being prolonged.
3. *Obtuse :* with a blunt or rounded apex.
4. *Truncate :* ending abruptly as if with the end cut off by a straight line.
5. *Retuse :* with a shallow notch in a rounded apex.
6. *Emarginate :* with a decided terminal notch.
7. *Mucronate :* ending abruptly in a short, stiff, sharp point.
8. *Cuspidate :* ending in a long, tapering, stiff, sharp point.
9. *Caudate :* ending in a long slender tail.
10. *Cordate :* when of two broad rounded lobes one on either side of a deep notch.
11. *Auricled :* when of two narrow rounded lobes one on either side of a deep notch.
12. *Sagittate :* when the lobes on each side of the notch are pointed and directed downwards.
13. *Hastate :* when the lobes on each side of the notch are pointed and directed outwards.

An ovate leaf which is cordate at the base and pointed at the apex is called a cordate leaf; similarly a leaf which is sagittate, or hastate, at the base and pointed at the apex is called a sagittate, or hastate, leaf. If in a lanceolate, ovate, or cordate leaf we imagine the petiole to be attached to the apex instead of to the base, we get an *ob-lanceolate*, *ob-ovate*, or *ob-cordate* leaf, respectively.

A *peltate* leaf is one in which the petiole instead of being attached to the margin of the leaf-blade is joined to some part of its under-surface, so that the leaf-blade is more or less at right-angles to the petiole, as in *Nelumbium speciosum*.

If in a deeply cordate leaf we imagine the basal lobes to grow together and join in front of the petiole we get a peltate leaf; if now such a cordate leaf was sessile on the stem and the same thing happened, the stem would appear to pass through the leaf. Such a leaf is said to be *perfoliate* and the base of the leaf which thus embraces, or clasps, the stem is said to be *amplexicaul*. If the base only partly surrounds the stem it is *semi-amplexicaul*. Occasionally the bases of two opposite sessile leaves grow together and are then said to be *connate*. In some cases the leaf-blade is continued along the stem below the leaf insertion and the leaf which thus seems to run down the stem is called *decurrent*, as seen in *Verbascum Thapsus*. Pinnately—and palmately—compound leaves are usually known as *pinnate* and *palmate* leaves, respectively.

The prolongation of the petiole of a pinnate leaf, which corresponds to the midrib of a pinnately-veined simple leaf, is called the *rhachis*.

When the rhachis terminates in an odd leaflet the leaf is said to be *impari*—, or *odd—pinnate* and when there is no terminal leaflet it is *pari*—, or *abruptly—pinnate*.

The leaflets of a pinnate leaf are usually opposite to each other in pairs, but sometimes they are alternate on the rhachis. The impari-pinnate leaves of Sissoo have alternate leaflets. When the leaflets of a pinnate leaf vary greatly in size the leaf is *interruptedly-pinnate*. When the terminal leaflet or pair of leaflets is largest, those below it gradually decreasing in size with the smallest at the base, the leaf is *lyrately pinnate*, as are the leaves of *Picrasma quassioides*.

When the rhachis of a pinnate leaf, instead of giving rise directly to leaflets, develops branches on which the leaflets are borne, these branches are termed *pinnae* and the whole leaf is said to be *bi-pinnate*, such as are the leaves of Khair (*Acacia Catechu*). When pinnæ, instead of bearing the leaflets

directly, also develop branches on which the leaflets arise, these secondary branches are termed *pinnules* and the leaf is said to be *tri-pinnate*, as are often the leaves of *Moringa pterygosperma.* A compound leaf is usually described by the number of leaflets, thus *bi-*, *tri-*, *quadri-foliolate* and so on.

It is not always easy at first sight to distinguish between a pinnately-and palmately-trifoliolate leaf, but on close inspection it will be seen that in the former the leaflets do not all spring from the same point—see the pinnately 3-foliolate leaf of *Desmodium tiliæfolium, Fig. 1, Plate V*, in which an obvious rhachis extends from the point of insertion of the pair of lateral leaflets to that of the terminal leaflet. The junction between the rhachis and the base of the terminal leaflet, or of its petiolule, is often marked by a distinct joint or articulation; sometimes also the petiolule of the terminal leaflet is swollen and is thus easily distinguished from the rhachis. The leaf of *Desmodium tiliaefolium* may be compared with the palmately 5-foliolate leaf of *Holboellia latifolia* in which all the leaflets spring from a distinct joint at the apex of the petiole, *Fig. 2, Plate V.*

It is not always easy to at once decide whether foliar structures are leaves or leaflets. If we look at a branch of *Phyllanthus Emblica* we find the small leaves arranged in two ranks along the twigs giving the latter the appearance of pinnate leaves. Minute buds may, however, be often found in the axils of these small leaves, thus indicating that they are true leaves, no buds being normally produced in the angle between a leaflet and the axis from which it springs. Moreover flowers are found on these leaf-bearing twigs thus showing that the latter are branches of the stem and not petioles, rhachises, or branches of them, on which no flowers normally arise.

A leaf which is at first palmately 3-nerved but in which each of the lateral nerves is forked, the outer branch of each fork sometimes again forking, is said to be *pedately-nerved.* Such a leaf may be lobed, cleft, parted, divided or compound, just as is the case with an ordinary palminerved leaf, and in the last case we get a *pedately-compound* leaf, which is usually simply called a *pedate* leaf. See *Fig. 7, Plate IV.*

The principal terms which are usually employed for describing the general shape of leaves have now been enumerated above, but it must be remembered that the forms of leaves are infinitely various and that it is neither possible nor desirable to have separate names and definitions for every form that may be met with. Here, as elsewhere, morphology

selects and describes types, and we must expect to find a number of forms intermediate between the types. For each intermediate form we employ the term which seems to describe it most correctly, and in many cases a combination of terms, such as *ovate-lanceolate*, *oblong-lanceolate*, and so on, are found to be most suitable. The student should collect leaves of various plants and endeavour to frame terse descriptions of the same, so that another person from the descriptions may be able to picture to himself the exact form of the leaves in question. On one and the same plant all the leaves are not exactly the same size or shape, and hence, when describing the leaves of the plant, the extremes must be given, such as "varying from ovate to elliptic, length of blade 4-6 inches, breadth 2-3 inches."

**Polymorphic Leaves.**

24. When the size and shape of the leaves on one and the same plant vary very considerably the plant is said to be *heterophyllous* and the leaves are said to be *polymorphic*. This is the case in many climbing plant ssuch as *Ficus pumila*, the Ivy and others, see *Figs. 1* and *2, Plate VI.*

To understand this phenomenon we must remember that the function of the green leaves, *viz.* that of manufacturing food for the plant, can only be properly performed when the green leaf-blades are exposed to the sunlight and cannot be carried out in the dark, and that the amount of food which can be manufactured depends on the amount of green surface exposed to the light. Creeping stems which are often found in shady places on the ground, or on the trunks of other trees, must make the most of the faint light at their disposal and must keep as large a surface of green leaf-tissue exposed to the light as possible. We thus find beautiful arrangements of leaves of very various size and shape, small leaves occupying the spaces between the large ones and the lobes and segments of some leaves fitting into the spaces between similar lobes and segments of adjoining leaves. Each leaf is thus arranged so as to shade its neighbours as little as possible and no light is allowed to pass through on to the substratum below without being utilised.

Such arrangements of leaves are called *leaf-mosaics*. When such creeping stems send up erect ærial stems standing away from the substratum covered by the leaf-mosaic and which ultimately give rise to flowers and fruit, the leaves borne by such stems usually differ considerably from those on the creeping stems and are more uniform in size and shape, see *Fig. 2, Plate VI.*

Such ærial stems are usually surrounded by brighter light than are the creeping stems and their leaves are exposed not only to overhead light, but also to considerable lateral illumination, so that in their case the partial shading of the lower leaves by the upper ones is not so important, the loss of overhead light being compensated by the addition of lateral light. Moreover as in such stems plenty of room is available to enable the leaves to develop at different levels it is not so necessary that the leaves arising at any one level should fit together closely and accurately, for the light which passes through the interstices of the upper leaf-layers may be received and utilised by the lower leaves and is not therefore lost to the plant. Hence in these shoots leaves of such size and shape as are necessary to form a close-fitting, more or less flat, mosaic are not required.

Although heterophylly is one of the expedients resorted to by plants in order to have as large a leaf surface as possible exposed to the light, it is by no means the only one, and in other plants the same end may be attained in a variety of ways.

**Leaves of Young Plants.**

25. The leaves of seedlings and young plants usually differ considerably from those of mature plants. *Fig. 5, Plate XII*, shows a seedling of *Oroxylum indicum* and indicates the difference which may exist between the first leaves and those subsequently developed, for the leaves there shown bear not the least resemblance to the enormous bi- and tri-pinnate leaves of the mature tree. The leaves of young plants of *Quercus semecarpifolia* have spines and are toothed, while on old trees they are usually entire, and in *Gardenia turgida* the leaves of young plants are quite unlike those of older plants. In species of *Phœnix* the leaves of young plants are usually entire while those of mature plants are pinnate. Similarly the leaves on coppice shoots often differ considerably in size and shape from those on uninjured plants. On coppice shoots of *Pyrus Pashia* the leaves are often lobed or cleft, whereas they are normally crenate. This point is one of practical importance for Foresters, who, unless they are able to recognise their trees and shrubs at different stages of their life-history, can know very little about the reproduction of their forests.

**Other Characters of Leaves.**

26. Leaves may be glossy or shining, like those of *Cocculus laurifolius*, or dull and not shining like those of *Euonymus Hamiltonianus* and in this, as in other respects, the upper and lower surface of the leaf-blade may differ considerably. As regards *colour*, mature

leaves are usually of some shade of green and the lower surface is frequently paler than the upper. The colour of young leaves is sometimes characteristic and is often of some shade of red or purple. As examples we may note the pinkish, or purplish, young leaves of *Quercus incana*, the bright red ones of *Acer caesium*, the beautiful purple and brown of those of Mango and the dark red brown of *Cassia Fistula.* Mature leaves frequently undergo a striking change of colour before they fall off the plant. Such colours are usually called autumn tints and often enable the Forester to recognise his trees from a long distance. As examples we may note: Colour.

The yellow of *Odina Wodier*, the pale leather-brown of *Lagerstrœmia parviflora*, the brick-red of *Antidesma diandrum*, the beautiful red, purple, and orange of *Sapium sebiferum*, and the dark red, or bronze, of *Anogeissus latifolia.* Some leaves, on drying, undergo a characteristic change of colour; those of *Dalbergia paniculata* turn black and those of many species of *Symplocos* turn bright yellow.

Smell. Many leaves have a strong and characteristic *smell* especially when they are crushed. As examples may be noted the unpleasant smell of leaves of *Viburnum foetens*, *Premna latifolia* and *Solanum verbascifolium*, the aromatic odour of those of *Skimmia Laureola* and *Cinnamomum Tamala*, the black-currant-like smell of *Pogostemon plectranthoides* and the well-known smell of *Thymus Serpyllum.*

Taste. The *taste* of leaves is also often peculiar. The leaves of *Bauhinia malabarica*, *Acacia pennata* and *Antidesma diandrum*, for example, have a characteristic acid taste.

Glands. Leaves which are strongly aromatic frequently have the ethereal oil, to which the smell is due, stored in small receptacles called *glands* in the leaf tissue. Such glands, being translucent, are easily seen when the leaf is held up to the light as pale spots. Such leaves are said to be *gland-dotted.* As examples may be taken a leaf of the Orange, or of *Zanthoxylum alatum.*

The texture of leaves, as well as excrescences, such as hairs, scales and so on, which commonly appear on other parts of the plant besides the leaves, will be considered later, when the detailed account of each member has been completed.

Characters of Petiole. 27. The principal points to be paid attention to as regards the petiole of the leaf are its length, which varies greatly in different plants, and its general shape. In some plants it is very slender and thread-like and is said to be *filiform*, in others it is stout. Like the

stem, the petiole may, or may not, be terete, flattened, angled, grooved, striate, and so on. Very frequently it is channelled, or grooved, on the upper surface as in *Viburnum cotinifolium*, see *Figs. 8* and *9, Plate IX.*

In some cases the lamina is continued along the sides of the petiole which thus appears to be winged, as seen in the Orange.

Leaf-Base.

28. In some cases the base of the leaf is more or less clearly differentiated from the rest of the leaf and in many plants it becomes a swollen cushion of tissue called the *pulvinus*, well seen for example at the base of the petiole of *Millettia auriculata*, and the small pulvinus often found at the base of leaflets is called a *pulvinule.*

This differentiation, however, is particularly remarkable in many Bamboos in which the leaf-base is large and forms a long sheath to the stem, the petiole of the lamina being separated from the sheath by a distinct joint or articulation. The sheaths which arise directly from the Bamboo culms, called the culm-sheaths, in the axils of which the branches arise, usually develop no leaf-blade, or only an imperfect one, but all gradations between sheaths with no blade and those with a normal lamina may frequently be seen.

This sheath is very characteristic of Bamboos and Grasses generally, as is also the peculiar structure known as the *ligule*, a membranous outgrowth developed from the inner face of the leaf-sheath at the junction of the lamina, or petiole, with the leaf-sheath, and which may be well seen in *Arundinaria falcata.*

In *Berberis Lycium* a distinct joint is found between the leaf-base and the lamina of the apparently simple leaf, see *Fig. 4, Plate V.* In *Berberis nepalensis*, however, a plant which in important characters resembles *B. Lycium* and which therefore, being considered to be fairly closely related to it, bears the name of *Berberis*, the leaves are pinnate and there is a distinct joint between the terminal leaflet and the rest of the leaf and at the insertion of the lateral leaflets, see *Fig. 3, Plate V*; hence it is concluded that the leaf of *B. Lycium* is really a compound, *i.e.* pinnate, leaf, reduced to the terminal leaflet. The apparently simple leaf of the Orange is also articulated to the petiole and is considered to be a unifoliolate compound leaf.

Stipules.

29. The leaf-base frequently develops two more or less noticeable lateral branches called

*stipules*, there being normally two stipules to each leaf, one on each side of the petiole. These are very large and leaf-like in *Albizzia stipulata* and the common Pea; sometimes they are like small bristles and are said to be *setaceous* and in *Capparis spinosa* they are developed as thorns. Stipules frequently fall off shortly after their first appearance and often before the leaf to which they belong is fully developed, as in *Holoptelea integrifolia.* In falling, however, more or less noticeable scars are left behind and by observing these it can be known that stipules were developed and an idea formed of their shape and size. The large stipules of many species of *Ficus* for instance leave ring-like scars.

In *Rosa* the stipules are adnate to the petiole. In some cases where the leaves are opposite a stipule of one leaf becomes united to the stipule which is opposite to it and which belongs to the other leaf on the node, there thus being apparently two large stipules at each node, situated between the petioles of the leaves. Such a stipule is called an *interpetiolar stipule* and is well seen in *Stephegyne parvifolia*, where each large stipule can be easily separated into its component stipules along their line of junction, see *Fig. 9, Plate VIII.*

In some plants in which there is only one leaf at each node, the stipules cohering by their outer edges, entirely embrace the stem and there is apparently one stipule opposite the leaf. In some cases the stipules cohere both by their outer and inner margins and thus form a complete tubular sheath around the stem, called an *ocrea*, as seen in many species of *Polygonum.*

The leaflets of a compound leaf often have stipules which are then called *stipels.* These may be seen in *Desmodium tiliaefolium, Fig. 1, Plate V.*

Leaves which produce stipules are said to be *stipulate* and those which do not are *exstipulate.* Similarly leaflets which produce stipels are described as *stipellate.*

Metamorphosed Leaves.

30. True leaves, like other organs, are often found to be metamorphosed, or altered in form, in order that they may be able to carry out other work than that usually performed by leaves. In *Gloriosa superba* the apex of the leaf-blade is prolonged and becomes a tendril, in the common Pea some of the terminal leaflets are transformed into tendrils, in *Clematis montana* the petiole coils round supports and serves as a climbing organ, in *Berberis Lycium* the entire leaf is often transformed into a three-

pronged spine and on one and the same shoot intermediate forms between the typical spine and normal foliage leaf can often be found, see *Fig. 3, Plate VI.*

That these spines are really leaves is indicated by the fact that buds and branches arise in their axils just as they do in the axils of true leaves; moreover the base of the spines is furnished with minute stipules just as are those of the normal leaves.

**Phyllotaxy.** 31. The way in which the leaves are arranged upon the stem is called *phyllotaxy*, or *phyllotaxis.* Some of the arrangements commonly found, such as opposite leaves, alternate leaves, and so on, have already been noted above, but it is usual to distinguish some additional types of the alternate arrangement by fractions, such as $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$ and so on. To determine the phyllotaxy of a plant one leaf is selected on the stem as a starting point which we may call (*a*) and then, passing up the stem, we note the first leaf which is situated exactly vertically above it which may be called (*b*). A spiral line is then traced from the starting point (*a*), passing the shortest way around the stem through the insertions of all the leaves situated between (*a*) and (*b*) in consecutive order and ending at (*b*). If this line is found to have passed twice around the stem and to have passed through 5 leaves, omitting (*a*) but including (*b*), the phyllotaxy is said to be $\frac{2}{5}$; if the line has passed three times around the stem through 8 leaves it is $\frac{3}{8}$ and so on. When alternate leaves are distichous, therefore, the phyllotaxy is $\frac{1}{2}$ and when they are tristichous, *i.e.* in three vertical ranks, it is $\frac{1}{3}$.

The phyllotaxy occasionally varies on one and the same plant; thus on erect branches of *Coriaria nepalensis* the leaves are decussate in 4 vertical ranks, whereas on horizontal branches, by a twisting of the stem, they become distichous and the leaves are also twisted so that their blades are practically horizontal, *i.e.* with the leaf-surface perpendicular to the direction of the rays of light coming from above, see *Plate XIII.*

We have noted already how important it is for plants to secure a suitable degree of illumination for their green leaf-surface, and this necessity is to a great extent responsible for the different forms of leaves and for the way in which they are arranged upon the stem. It must, however, always be remembered that all plants have not identical requirements, that, for instance, the most suitable degree of illumination for one plant may be injurious to another, and secondly that the

same object may be attained by different plants in entirely different ways. Thus one plant may obtain the best illumination for its foliage by heterophylly, another by adopting a different arrangement of the leaves upon the stem, or by varying the lengths of the petioles, another by adopting a climbing habit, and so on.

32. Buds normally arise in the leaf axils, or at the apex of the stem or branches. Those arising elsewhere are adventitious. Some buds contain only rudimentary foliage leaves, others rudimentary flowers and some both rudimentary leaves and flowers. Buds.

If we examine an ordinary foliage bud, especially when it is bursting into vigorous growth, we can easily satisfy ourselves that it is merely a young stem, or branch, bearing the as yet imperfectly developed leaves and with very short internodes.

Some buds are covered with dry scales which protect the delicate young parts within them from being dried up and killed; these are well seen in the large buds of the Horse Chestnut, *Aesculus indica.* The bud is often still further protected by a coating of wax, gum, or resin, while the young parts inside the scales are also often protected by a covering of wool, or hair. Other buds have no protecting scales and are said to be naked, *e.g.* those of Teak. If we watch the development of a scaly bud we find that, shortly after the bud opens and begins to grow vigorously, the scales which previously covered and protected it fall off, leaving behind several small scars close together on the stem, indicating the spots where they were inserted. These can be well seen in *Fig. 1, Plate VII*, which shows a twig of *Acer caesium* from the terminal bud of which 4 leaves have developed, the bud-scales having just been shed. In all trees and shrubs therefore in which the growth of stems and twigs is stopped once annually, scaly buds being produced at their apices during the period of rest, it is clear that we can calculate their age, so long as these scars of the bud-scales are visible. In *Fig. 1, Plate VII*, for instance, the twig shows the completed growth of 3 years, while that of the 4th year has just commenced. In the spruce, *Picea Morinda*, the bud scales do not fall off singly, but cohere, and are carried up like a cap on the tip of the young expanding shoot.

In connection with this question of the age of shoots should be noted also the fact that in Pines one whorl of lateral branches is usually developed each year, so that the age of

branches and young trees can be calculated by counting such whorls, allowance being of course made in the case of stems for the number of years required before the first whorl is formed on the seedling. There are, however, exceptions and unusual conditions may cause the development of more than one whorl in the year, but it is important to note this as an example of what may be done by carefully watching the development of different species. Bud scales are sometimes metamorphosed leaves. If we examine an opening bud of *Aesculus indica* we find that, while the outermost scales remain dry and fall off, some of the inner scales begin to grow and those which grow the most very closely resemble normal leaves. *Figs. 1—8, Plate VIII*, give a series of such scales removed from an opening bud which clearly shows the bud-scales to be normal leaves which have been arrested in their development and made to function as a protective covering to the other young leaves. *Fig. 2, Plate VII*, shows a young shoot developing from the bud of *Carpinus viminea*, and in this case the bud-scales are seen to be stipules, the inner scales being situated one on each side of a leaf petiole just as are normal stipules. The bud-scales of species of *Ficus* are also found to be stipules and in *Stephegyne parvifolia* the large interpetiolar stipules act as bud-scales, see *Fig. 9, Plate VIII*. All the buds which are formed on a plant do not necessarily develop ; in many cases a large number remain dormant for long periods and develop only under exceptional circumstances, such as when neighbouring buds, or young shoots, are destroyed, such resting buds are termed *dormant buds*.

Usually there is only one bud in each leaf axil, but not infrequently there are additional buds situated on each side of, or above, the true axillary bud ; these are termed *accessory buds*. In some cases these are obviously only the lowest buds of a normal axillary shoot, which, at first sight, appear to spring directly from the parent stem, owing to the lower nodes of the axillary shoot remaining very short.

In *Prinsepia utilis* there is frequently an accessory bud which develops into a spine and serves as a protection to the axillary bud below it, see *Fig. 10, Plate VIII*. Buds which arise outside of the leaf-axil are termed *extra-axillary*.

Buds vary greatly in size, shape, colour, in the number of their external scales and other characters which are useful for identifying deciduous trees and shrubs in the forest.

In the Plane, *Platanus*, the buds are found to be completely covered by the hollow base of the petiole and only become

visible when the leaves fall off, a characteristic circular scar around the bud then showing where the leaf was inserted.

33. The way in which the young leaves, or leaflets, are folded in the bud, which is called *vernation*, varies in different species. In some cases the edges of the leaf are rolled in towards the midrib on the upper surface of the leaf when the vernation is *involute*. In other cases the edges are similarly rolled in towards the midrib on the under surface, the vernation being *revolute*. In others the leaf is not rolled and the longitudinal halves of the blade, turning on the midrib like a hinge, are placed flat face to face with their upper surfaces in contact, the vernation being *conduplicate*. In others the leaf is so folded on its longitudinal axis that the under-surface is outside and one edge covers the other, the vernation being *convolute*. In others the leaf is coiled inward from the apex, the vernation being *circinnate*. In others the leaf-blades are folded between the nerves, the vernation being *plicate*. **Vernation.**

For illustrations see *Plate IX*.

Finally, in some cases, there is no obvious folding, or rolling, and the young leaves are placed practically flat, or slightly curved, one against another.

A young leaf in the early stages of its development has its tissues imperfectly developed, and the soft green tissue lying between the nerves is particularly susceptible to injury and is liable to be dried up and destroyed if fully exposed to the sun and air.

Some protection is therefore commonly provided for it, sometimes by the folding of the lamina, sometimes by the position assumed by the young leaves, and sometimes by protective coverings of hair, wax, gum, or resin.

Thus in *Viburnum cotinifolium* we find the young leaves erect on the stem, each pair of opposite leaves having their upper surfaces placed close together, while only the under surfaces are exposed to the light and air.

The upper surface of each leaf is concave, the under surface convex, and the lamina is plicately folded, the delicate green tissue being thrown into deep folds between the nerves, these folds projecting into the concavity of the upper surface. Thus the green tissue is effectively protected during its early development by the close-set framework of nerves which alone are exposed on the exterior of the young leaves. As the young leaves are thus erect and closely adpressed, we find that the upper surface of the petioles is grooved, room being thus provided for the terminal bud between the opposite leaves.

As each leaf gets older the folds of green tissue are flattened out, the leaf is thrown outward and downward and the lamina is expanded more or less horizontally, with the upper surface directly exposed to the sun's rays. See *Figs. 7—9, Plate IX.*

**Homologous and Analogous Members.**

34. Several cases of the so-called metamorphosis of plant members have been incidentally mentioned in this and the previous chapters from which it will be seen that members which are alike in their mode and place of origin and general plan of structure are regarded as morphologically the same, however different they may superficially appear to be in their form, or function. Members which are thus of the same morphological value are said to be *homologous*, whereas those members which, although alike in some respects, are not morphologically the same, such as the spines of *Berberis* and Bel, are called *analogous*.

## Chapter IV.—THE INFLORESCENCE AND FLOWER.

35. A shoot which bears a flower is called a *flowering-shoot*, and like an ordinary leafy shoot it may be *axillary*, or *terminal*. In some species the flowering shoots spring from the older branches, or stems, from which the leaves have disappeared, as in *Ougeinia dalbergioides* and *Ficus Cunia*. Flowering-Shoot.

The flowering shoot frequently branches and produces, not one, but several flowers. The collection of flowering shoots thus formed is the *inflorescence*. According as the flowering shoots are stiff and erect, or drooping and pendulous, so is the inflorescence described as *erect*, or *pendulous*. The inflorescence varies greatly in size: in the Teak it is very extensive and is then described as *ample*, or merely large, whereas in other cases it is reduced to a few small flowers, or even to a single flower, in which case the flowers are *solitary*, and the inflorescence may be further said to be *many-* or *few-flowered*, and *much-branched* or *little-branched*. Again if its branches are close together the inflorescence is *compact*, or *dense*, otherwise it is *lax*, or *loose*. Inflorescence.

The first important point to notice regarding the flowering shoots is that the leaves which they bear, and from the axils of which they spring, are usually smaller than the ordinary foliage leaves, of a different shape and sometimes also of a different colour. Such altered leaves are called *bracts*. Those which are borne on the ultimate branches of the flowering shoots, *i.e.* on the stalks of the individual flowers, are distinguished by the name of *bracteoles*. A flowering shoot on which bracts are produced is said to be *bracteate*, if no bracts are produced it is *ebracteate*. Bracts.

The stalk of a flower is the *peduncle*; when the peduncle branches, that portion of it from which the lateral flowering branches arise is the *rhachis* and the stalks of the single flowers are then called *pedicels*, terms which will recall the analogous ones of petiole, rhachis and petiolule employed for the leaf. Stalked flowers are said to be *pedunculate*, or *pedicellate*, as the case may be, while flowers without a stalk are *sessile*. Peduncle. Pedicel.

36. We have seen above that there are two principal kinds of branching, *viz.*, monopodial and cymose, and according to the way in which the flowering Types of Inflorescence.

shoot branches two main types of inflorescence are distinguished as under, although here, as in other cases, intermediate forms are found :

(1) *Monopodial* or *racemose.*—Here there is a distinct main axis formed by the continued elongation of the parent flowering shoot.

(2) *Cymose.*—Here there is no main axis formed by the elongation of the parent flowering shoot and lateral flowering shoots grow more vigorously than the parent axis.

The principal kinds of racemose inflorescences are :—

(*a*) *Raceme.*—The main axis is elongated and bears pedicellate flowers.

(*b*) *Corymb.*—This is a raceme in which the main axis is short and the lower pedicels are longer than the upper ones, the inflorescence being more or less flattened and with a convex outline.

If in a raceme, or corymb, the main axis, instead of directly producing pedicels, develops lateral branches which, directly or indirectly, bear the pedicels, we get a *compound-raceme* or *-corymb*, respectively.

(*c*) *Spike.*—The main axis is elongated and bears sessile flowers. A small spike is called a *spikelet.* A spike having inconspicuous unisexual flowers and which falls off entire from the plant after flowering, or fruiting, is a *catkin.* It is usually pendulous.

(*d*) *Spadix* is a spike with a thick or fleshy axis. A spadix is usually more or less enclosed in a large bract which is called the *spathe.* In palms the spadix is branched and has several spathes.

(*e*) *Umbel.*—The main axis bears a number of pedicellate flowers at its apex. The pedicels which all radiate from the same point are called the *rays* of the umbel. At the apex of the peduncle bracts are often found forming a whorl below the pedicels, or rays, which is called the *involucre.* When the rays instead of bearing flowers bear secondary umbels, the latter are termed *umbellules* and their involucres are *involucels,* while the inflorescence becomes a *compound umbel.*

(*f*) *Head* or *Capitulum.*—The main axis bears a number of sessile flowers at its apex. Here also there

is usually an involucre of bracts below the flowers. The apex of the peduncle on which the flowers are borne and which is really the shortened rhachis is here called the *receptacle* of the inflorescence. Small scale-like bracts are often found on the receptacle subtending the individual flowers.

In a typical raceme there is no obvious reason why the main axis should not continue to grow and produce lateral branches in acropetal succession indefinitely, whereas if it soon produced a terminal flower, as is the case in a cyme, its growth is at once checked and the further development of the inflorescence then devolves on the lateral branches. Racemose inflorescences are therefore often called *indeterminate*, or *indefinite*, and cymose inflorescences *determinate*, or *definite*. Again if a plan is drawn of a raceme the youngest flowers are in the centre and the oldest are outside, while a line following the course of development from the oldest to the youngest flowers of such an inflorescence passes from the outside to the centre, whereas in a cyme the reverse is the case, the oldest flower being in the centre. Hence racemose inflorescences are called *centripetal* and cymose inflorescences *centrifugal*. In the case of inflorescences in which the shoots are much reduced in length and the flowers are therefore brought together more or less at the same level, it is often not easy to decide to which type they must be referred and the relative position of the flowers then often helps us to decide the question. In a head, for instance, the facts that the oldest flowers which open first are on the outside and that the youngest which open last are in the centre, indicate that the inflorescence is racemose. A compound racemose inflorescence also is usually easily recognised by the fact that there is a distinct main axis with the oldest and longest branches at its base and the youngest and shortest at the apex.

The principal kinds of cymose inflorescences are :—

(*a*) *Dichotomous cyme.*—The main axis terminates in a flower and two vigorous and equal lateral branches develop. If there are three equally vigorous lateral branches instead of two the cyme becomes *trichotomous*. If this kind of branching is continued and each lateral branch in its turn terminates in a flower and in its turn develops 2 or 3 vigorous lateral branches and so on, the inflorescence becomes a *compound di-* or *tri-chotomous cyme* respectively.

(*b*) *Helicoid cyme.*—The main axis here terminates in a flower as before, but the further growth of the inflorescence is carried on, not by 2 or 3 equally vigorous lateral branches, but by one only, the latter also soon terminates in a flower and produces another lateral branch and so on, the lateral branches always developing on the same side of the parent axis.

(*c*) *Scorpioid cyme.*—This is similar to (*b*) but the lateral branch, instead of always developing on the same side of the parent axis, develops alternately on opposite sides.

In both (*b*) and (*c*) there is thus a sympodium, or false axis. When this false axis straightens, as it usually does, the inflorescence has a strong superficial resemblance to one of the racemose type. In such cases the position of the bracts often indicates at once the true character of the inflorescence, for the flower stalks, instead of springing from the axils of the bracts, as they would do in a raceme, are opposite to the bracts.

A *Fascicle* is a general term for a tuft or cluster of flowers, or of flowering shoots, without reference to its being of the racemose or cymose type, and is used when the true character of the inflorescence is not easily made out.

*Panicle* is a much used term which is applied to all compound and much branched inflorescences of which the first ramifications are racemose. A panicle which is ovate or lanceolate in outline is called a *thyrsus.*

A cyme which, in outline and general appearance, resembles a raceme, corymb, or umbel, is called a *racemiform, corymbiform*, or *umbelliform* cyme, and similarly a panicle may be *racemiform, corymbiform*, or *umbelliform.*

For illustrations of some of the above types of inflorescences see *Figs. 1 to 10, Plate X.*

Finally there are the more complicated so-called *mixed inflorescences* in which more than one type is combined. Thus the ultimate ramifications of a panicle, the first branches of which are developed according to the racemose type, may be cymes, and such a panicle may be described as a *cymose panicle*, or, perhaps better, we may describe the inflorescence as one consisting of cymes arranged in a panicle.

If the student will examine for himself the following examples of typical inflorescences, they will help him to

realise how the above terms may be employed in practical descriptive botany :—

(1) *Lax, long, pendulous racemes* of *Cassia Fistula.*
(2) *Dense, pedunculate racemes* of *Abrus precatorius.*
(3) Flowers of *Desmodium pulchellum* in small *fascicles* in the axils of 2-foliolate bracts arranged in *terminal* and *axillary racemes.*
(4) *Few-flowered corymb* of *Dolichandrone, falcata.*
(5) *Spike* of *Terminalia belerica.*
(6) *Spadix* of *Arisaema Wallichianum,* the Cobra Plant.
(7) *Fascicled heads* of *Acacia Farnesiana.*
(8) *Compound trichotomous cymes* of *Eugenia operculata.*
(9) Flowers of *Trewia nudiflora fascicled in pendulous racemes.*
(10) *Many-flowered umbelliform cymes* of *Leptadenia reticulata.*
(11) *Sessile* flowers of *Wendlandia exserta,* in large *conical,* or *pyramidal, panicles.*
(12) *Panicle of heads* of *Acacia caesia.*
(13) *Panicle of umbels* of *Heptapleurum venulosum.*
(14) *Dichotomous cymes* of *Cornus macrophylla* in large *terminal panicles.*
(15) *Heads* of *Albizzia odoratissima* in *compact corymbs,* arranged in large *panicles.*
(16) Compact *thyrsus* of *Phlogacanthus thyrsiflorus.*

**Parts of the Flower. Perianth, Stamens, Pistils.**

37. In a typical flower we can at first sight distinguish 3 obviously distinct kinds of organs; the outer ones are more or less clearly leaf-like in shape, often with a distinct venation and sometimes green in colour. These may be called the *floral envelopes* and together constitute the *perianth.* One of the important duties which the perianth has to perform is to envelop and protect, especially when they are young, the essential floral organs situated within them and which are the *stamens* and *pistils.* The former together constitute the male portion of the flower, called the *andrœcium,* and the latter the female part, called the *gynœcium.* A typica stamen consists of a swollen head called the *anther,* situated on a slender stalk called the *filament.* In the anther is stored a yellow powdery substance called *pollen,* contained in two little bags which are placed side by side in the anther and which, when the anther is mature, open and scatter the pollen. This opening is termed the *dehiscence* of the anther. A typical single pistil consists of a swollen hollow, base, called the *ovary,* which contains the small rounded bodies called *ovules* (these

eventually developing into what are known as *seeds*), an elongated neck called the *style*, which is frequently more or less expanded at its apex and there forms the so-called *stigma*. The stigma is a specially differentiated part of the style, usually with a moist and sticky surface, which varies greatly in shape and size; sometimes it is a rounded knob; sometimes it is merely a single, or double, line running along the side of the style, while sometimes the apex of the style is forked and the sticky surface of the stigma (called the *stigmatic surface*) is found on the branched tip of the style. The essential parts of the pistil are the ovary and the stigma. The style may be, and often is, absent, the stigma then being *sessile*. The ovary being the principal part of a pistil, the word ovary is often used to signify the whole pistil. A flower may contain one or several pistils.

Torus or Receptacle.

The perianth leaves, stamens and pistils are all inserted close together on the more or less expanded apex of the flower-stalk and this portion of the stalk from which the floral organs spring is called the *torus*, or floral *receptacle*.

Pollination and Fertilisation.

38. The object of the flower is to produce seeds which are capable of developing new and independent plants. No seeds, however, can arise in a pistil unless some of the powdery pollen which is contained in the anthers is able to reach the stigma. The small grains of pollen which happen to be caught by, and to adhere to, the sticky stigma develop minute tubes which penetrate the style and grow down into the ovary to the ovules, the contents of each pollen grain passing into its tube. When one of these tubes reaches an ovule, a part of its contents pass into and fuse with a part of the contents of the ovule, which is then said to have been *fertilised* and which thereafter grows and develops into a seed, containing the embryo of a new plant. The transference of pollen to the stigmas (*pollination*) is thus of vital importance, it being essential for fertilisation and the production of seeds. In some plants such as Grasses, this is done by the wind and these plants have no conspicuously-coloured flowers; in other plants this work is done by insects and birds who visit the flowers for the sweet juice, or nectar, which they contain, get dusted by pollen in the process, and carry this away to the stigmas of other flowers. Those flowers which can be most easily seen and found by birds and insects obviously therefore have the best chance of being visited and of having their ovules fertilised, and this is the reason why so many flowers possess conspicuous and brightly

coloured perianth leaves and attractive scents. From this we see that, however conspicuous the perianth leaves of a flower may be, these are after all of only subsidiary importance and that the really essential organs of a flower are the stamens and pistils, without which no seed can be formed. There are indeed some flowers which only contain each a single pistil, or a single stamen, but which nevertheless must be regarded as true flowers.

39. The perianth of a flower may consist of leaves which are all alike, or it may consist of two distinct sets of leaves, the outer of which are usually green and the inner of more delicate texture, and, being white, or of some colour other than green, the latter serve to make the flower conspicuous. The former are called *sepals* and together constitute the *calyx*, the latter are the *petals* and together constitute the *corolla*. In *Rosa moschata* for instance, we find no difficulty in distinguishing the inner 5 large white petals from the outer green sepals. Perianth.

A flower which has both sepals and petals is said to be *dichlamydeous*, one which is without both sepals and petals, *i.e.* with no perianth, is *achlamydeous*, while one which has only sepals, or only petals, is *monochlamydeous*. A flower which has no petals is also said to be *apetalous*. When the perianth leaves are all similar and there is therefore no obvious calyx and corolla, the leaves are merely called perianth leaves. If they are all coloured like petals the perianth is said to be *petaloid*, whereas if they all resemble sepals the perianth is *sepaloid*. If the perianth, calyx, or corolla, of a flower consists of distinct leaves, which are separate from one another and each of which has a distinct insertion of its own upon the receptacle, the perianth, calyx, or corolla, respectively, is said to be *polyphyllous*, *polysepalous*, or *polypetalous*. On the other hand a perianth, calyx, or corolla, of united, or *connate*, leaves, is said to be *gamophyllous*, *gamosepalous*, or *gamopetalous*. According to the degree of cohesion between the respective perianth leaves, sepals, or petals, they are said to be *connate at the base*, *to* or *beyond the middle*, *nearly to the apex*, and so on.

In cases of cohesion, where there is a distinct narrow base formed by the lower connate portions of the leaves, this is called the perianth-, calyx-, or corolla-*tube* and the upper expanded portion is called the *limb*. The intermediate portion, usually slightly more expanded than the tube and not so much expanded as the limb, is called the *throat*. The calyx or

corolla is also said to be *toothed* when the sepals or petals are united nearly to the apex, *cleft*, or *lobed*, if divided to about the middle, and *parted* if divided nearly to the base. The same terms may also be used for the perianth.

**Position and Number of Parts of the Flower.**

40. When both calyx and corolla are present the number of sepals is very frequently equal to the number of petals. The organs of the flower are usually inserted in whorls on the receptacle; the internodes between the whorls being as a rule very short, the whorls are all brought close together and the members of successive whorls are seen to alternate with each other. Thus we find an outer whorl of say 5 sepals and then, inside and above them on the receptacle, a whorl of 5 petals so arranged that each petal stands in the gap between two sepals, then inside the petals a whorl of 5 stamens alternating with the petals and each stamen therefore opposite a sepal, then another and inner whorl of stamens alternating with the outer and each of its stamens therefore opposite a petal, and finally the pistil, or pistils. Some flowers have a whorl of bracteoles outside the calyx, which at first sight may be mistaken for an extra whorl of sepals. By carefully counting the obvious petals and sepals, however, their true nature may usually be detected. Thus in a flower of *Hibiscus Rosa-sinensis* we find, outside the stamens, 5 large red obvious petals and then a gamosepalous calyx of 5 connate sepals alternating with them. In addition to these, however, we find 6 or 7 linear bracteoles. If the latter formed a normal whorl of sepals they would be 5 in number alternating with the whorl above, which they do not, but even if they were 5 in number and did correctly alternate with the sepals above them, by including them among the sepals the latter would become twice as numerous as the petals, which is unusual. Again in the cotton plant (*Gossypium*) we find an obvious corolla outside the stamens composed of 5 large yellow petals with a purple centre and a gamosepalous calyx of 5 connate sepals and then 3 large leafy bracteoles just below the calyx. One or more whorls of bracteoles which in this way resemble an outer calyx of a single flower form what is called an *epicalyx* and remind us of the so-called involucre of bracts at the base of a head or umbel of several flowers.

What has been just said must of course not be taken to mean that in a flower, in which both calyx and corolla are present, the number of sepals must equal the number of petals and the members of each whorl must alternate with those of the next, as there are obviously several flowers in which this is not

so, such as those of the Poppy, in which there are 4 petals and 2 sepals. The fact is only here emphasized that this is the case in a very large number of plants and the fact will often be found useful in helping us to readily diagnose flowers in the field.

If now we look at a flower of *Berberis Lycium* we find, outside the 6 stamens, 12 perianth leaves, the inner 6 of which are all the same size and colour and at first sight appear to be in one whorl with a stamen in front of each of them. The outer 6 perianth leaves, however, are distinctly arranged in two whorls, each of 3 leaves, the outer 3 being greenish and sepal-like alternating with the 3 inner leaves which are larger, brighter yellow, and obviously more like petals. If we examine the flower more carefully and remember that as a rule the number of sepals and petals is equal, we find that it is really quite normal with 2 whorls each of 3 sepals, 2 whorls each of 3 petals and 2 whorls each of 3 stamens, the members of each whorl alternating with those of the next. In this case the outermost 3 leaves are more or less obviously sepal-like, but the 3 leaves in the next whorl are undoubtedly more like typical petals, and this indicates that the only real difference between sepals and petals is one of position, the former being the outer and the latter the inner set. Outside the outer whorl of sepals there are usually also 2 or 3 small bracteoles which closely resemble the outer sepals, and we see that, so far as mere appearance goes, it is not always possible to readily distinguish bracteoles from sepals. A flower which has its parts in whorls of 2, 3, 4, 5, or 6 respectively is said to be *di-*, *tri-*, *tetra-*, *penta-* or *hexa- merous.*

According as the number of stamens in a flower is one, two, three, or many, it is said to be *mon-*, *di-*, *tri-*, or *poly-androus.*

**Distribution of Sexual Organs.**

41. A flower which contains both stamens and pistil, or pistils, is said to be *hermaphrodite*, or *bisexual* ; a flower which either has no stamens, or no pistil, is *unisexual*; a unisexual flower with stamens is a male, or *staminate*, flower, and is usually shortly written thus — ♂ *flower*, while one with pistils only is a female, or *pistillate*, flower and is written ♀ *flower.* When the flowers of a plant are unisexual but both ♂ and ♀ flowers occur on the same individual plant, the flowers are *monœcious* and the plant itself may be described as *monœcious.* When the flowers of a plant are unisexual and the ♂ and ♀ are found on different individuals the flowers and plant are said to be *diœcious.* When the flowers of a plant are both unisexual and hermaphrodite, which may, or may not, occur

on the same individual, the plant and flowers are said to be *polygamous*. A flower which produces no seed is said to be *sterile*; this may be because it possesses no pistil, or because its pistils fail to produce seed.

Symmetry of Flower.

42. A flower is normally borne in the axil of a bract which is said to subtend the flower, just as an ordinary foliage leaf subtends its axillary branch. That part of the flower which faces the flowering shoot from which it springs laterally is called the *upper*, *superior*, or *posterior*, while the opposite part facing the subtending bract is the *lower*, *inferior*, or *anterior*. The plane which passes through the posterior and anterior part of the flower, and therefore through the parent flowering axis and the middle of the subtending bract, is the *median plane*, or *section*, of the flower, while a vertical plane passing through the flower at right angles to the median plane is called the *lateral plane* or *section*, and any other plane which passes through the intersection of these may be called the *oblique plane* or *section*.

A radial *longitudinal section* of a flower is one which is parallel to its longitudinal axis and passes through the centre of the flower, while a *transverse section* is one at right angles to its longitudinal axis.

If in a flower the members of each whorl of floral organs are all alike in size and shape, the flower is *regular*. If not it is *irregular*. The regularity or otherwise of a flower is naturally most noticeable in the perianth leaves and especially in the corolla, these being as a rule the most conspicuous part of the flower, and hence when in descriptive botany a flower is spoken of as regular, or irregular, these terms may as a rule be taken to refer to the corolla, or perianth leaves.

A flower which is divisible in two or more radial longitudinal planes into similar halves, so that in each section one half is to the other as an object is to its image seen in a mirror and the halves in one section are similar to those in the other sections, the flower is *actinomorphic*. When there is only one radial longitudinal section in which a flower can be divided into similar halves it is said to be *zygomorphic*, and if there is no plane in which it can be divided in this way it is *asymmetric*.

The Parts of the Flower are Leaves.

43. The flower is really a shortened shoot and its parts, which compose the calyx, corolla, androecium and gynoecium are really nothing but leaves. The flower bud like the bud of an ordinary leafy shoot is either terminal, or it arises in the axil of a leaf, the latter being a normal green leaf, or one which has only been

slightly altered in character in which case it is called a bract. The green sepals are often large and obviously leaf-like; the petals also in shape more or less resemble leaves and they often have a distinct venation. Colour alone is a characteristic of very little importance in enabling us to decide on the true nature of a member, as is shown by the fact that the bracts of several plants, although they are obviously leaves, are brilliantly coloured like petals, *e.g.* the bracts of *Bougainvillea.* The remarkably conspicuous pure white, or coloured, calyx lobe of *Mussaenda* should also be noted. Stamens it is true do not at first sight at all remind us of leaves, but in some flowers, especially in those which have numerous petals, as in the Water Lily (*Nymphaea*), we find that the petals gradually pass into the stamens through a series of intermediate forms, which clearly indicate how one and the same organ may, by a number of slight modifications, become a normal, more or less leaf-like, petal, or a perfect stamen.

The pistil also does not at first sight resemble a leaf, but if we take a simple pistil such as a young pea-pod, and compare it with an involutely-folded leaf, the margins of which are brought together and made to cohere, we see that very slight modifications would, after all, suffice to convert what would ordinarily develop into a normal leaf into a pistil.

Occasionally also, *e.g.* in Roses, examples may be found of so-called "green-flowers," in which the different members, instead of assuming their ordinary shape and colour, appear as more or less perfectly developed green leaves. The facts noted above which indicate the true nature of the floral members are found to be confirmed by a microscopic examination of their mode of origin, minute structure and development during the early stages of their growth, when they are found to be indistinguishable from true leaves. The floral parts arise on the flower stalk just as leaves do, on an ordinary shoot. Occasionally they are in spirals, but as a rule they are arranged in whorls. The internodes in the flower usually remain very short, and all the floral parts are therefore crowded close together on the portion of the shoot from which they spring, *i.e.* on the so-called receptacle, or torus. This, however, is not always the case, and in *Capparis* there is a distinct internode between the stamens and the pistil, the latter appearing to have a stalk which is called the *gynophore*; internodes are also occasionally developed between other floral parts, *e.g.* between the petals and stamens in species of *Grewia*, and a stalk which thus appears to bear both the stamens and the pistil is called a *gonophore.*

Although the apex of the floral axis as a rule ceases to grow at a very early stage in the development of the flower, exceptional cases are known in which this axis has continued to grow, and we find a green leafy shoot growing apparently out of the centre of the flower. Very rare cases are also known in which buds have been developed in the axils of the floral members, just as they are usually developed in the axils of normal leaves.

Cohesion. Adhesion.

44. Owing to the very limited growth of the floral axis and to the non-development of its internodes the floral parts are, as has already been noted, crowded close together and in many cases this crowding results in the young members, which originate separately on the receptacle, coalescing at their bases, and they then grow up together instead of separately. This is how a gamosepalous calyx, or a gamopetalous corolla, for instance, arises. When members belonging to the same whorl become thus fused together the phenomenon is termed *cohesion* and the members are said to be *connate.*

Members belonging to adjacent whorls also often become fused together and we find, for example, stamens fused with petals, the stamens looking as if they had grown out of the corolla. In such a case we say there is *adhesion.* Members which are thus *adnate* appear to originate not directly from the receptacle in the usual way but at some distance from it, their apparent point of insertion having been carried, as it were, away from the receptacle. Cohesion then is the union of members belonging to the same whorl, adhesion the union of those developed at different levels, while members which are neither connate nor adnate are said to be *free.*

Hypogynous, Perigynous, Epigynous Flowers.

45. When there is no adhesion and the sepals, petals and stamens all arise directly from the receptacle, these members obviously originate directly *below* the gynœcium. The sepals, petals and stamens are then said to be *hypogynous*, or *inferior*, and the gynœcium is free and *superior*. The entire flower may also be described as hypogynous. When, however, there is some degree of adhesion and the petals and stamens, instead of springing from the receptacle, appear to spring from the calyx-tube, the apparent insertions of the sepals, petals and stamens are no longer directly below the gynœcium, but are carried out away from the receptacle and form a circle around the gynœcium. In this case the sepals, petals and stamens are *perigynous* and the flower itself is said to be perigynous. Here, however,

there is no adhesion between the gynœcium and the other floral members, the gynœcium is still quite free from the latter and is superior. Finally, there are cases in which the other floral members are united with the gynœcium and in which the adhesion is carried right up to the top of the gynœcium, so that the latter appears to be completely enclosed and covered in, while the sepals, petals, and stamens appear to arise on the top of, or above, the gynœcium. The sepals, petals and stamens are here said to be *epigynous*, or superior, the flower itself is epigynous and the gynœcium is *inferior*. For illustrations see *Figs. 11—14, Plate X*. The typical cases noted above are linked together by a number of intermediate forms; thus in some flowers there is adhesion between the gynœcium and the other members, but this adhesion only extends about half-way up the gynœcium. Such flowers are best considered as imperfectly epigynous, and the gynœcium may be described as *half-inferior*. In the case of other flowers, where the insertions of the petals and stamens are only very slightly removed from the receptacle, it is often difficult to decide if they should be classed as hypogynous or perigynous. The fact that, sometimes, the so-called calyx-tube is found to bear rudimentary leaves, indicates that this is, in many cases, really an outgrowth of the floral axis, or receptacle, and that it does not consist merely of the coalescent bases of the sepals and other floral leaves.

**The Disc.**

46. The torus, or floral receptacle, frequently grows out and forms what is called a *disc*, this being merely an expansion of the receptacle. It is usually a fleshy, swollen ring of tissue which may, or may not, be lobed, or divided. When the disc is divided into distinct portions the separate parts of it are termed *glands*. The disc and glands frequently excrete a sweet, sugary fluid commonly known as nectar and each is then called a *nectary*. The disc is usually developed between the stamens and the gynœcium, but sometimes also between the petals and stamens, and sometimes it bears the insertions of the petals and stamens. According to its apparent place of origin, the disc may be hypogynous, perigynous, or epigynous.

**Descriptive Terms for Petals and Sepals.**

47. In addition to the terms which have been already given for ordinary leaves, the following are often used for describing the shape of sepals and petals. If they have a narrow base supporting a broad expanded blade, the former is termed the *claw* and the latter the *blade*, or *lamina*. If strap-shaped they are termed

*ligutiform.** Sometimes there is an outgrowth from the inner face of the petals, usually at the junction of the blade and claw, or at the throat of a gamopetalous corolla, which is often scale-like and reminds one of the ligule of Grasses. Such outgrowths in a flower, collectively, constitute the so-called *corona*.

The calyx or corolla is said to be :—

*Bi-labiate*, if divided into two more or less distinct lips.

*Rotate*, or *wheel-shaped*, when with a spreading limb and very short tube.

*Crateriform*, or *cup-shaped*, when like rotate but with the limb curving upwards.

*Hypocrateriform*, or *salver-shaped*, when with a long narrow tube, abruptly expanding into a broad limb.

*Trumpet-shaped*, if salver-shaped with the tube expanding near the top.

*Infundibuliform*, or *funnel-shaped*, when the tube expands gradually from the base.

*Campanulate*, or *bell-shaped*, when the tube is expanded from the base, with its length not more than twice its breadth and with the sides spreading outwards at the top.

*Urceolate*, or *urn-shaped*, when the tube is swollen in the middle and contracted at the top and base.

*Tubular*, when there is a conspicuous nearly cylindrical tube and a relatively inconspicuous limb.

*Gibbous*, when with a small pouch-like swelling near the base.

*Ventricose*, when swollen on one side, like the corolla of several species of *Strobilanthes*.

*Saccate*, when swollen at the base like a bag.

*Spurred*, when with a slender, hollow prolongation.

The limb or lobes of the calyx are sometimes reduced to hairs or bristles which are often branched and feathery and which constitute the so-called *pappus*. The calyx in such a case is said to be *pappose*. The pappus is often more or less invisible in the flower and only becomes fully developed when the fruit ripens, as is the case in *Valeriana Wallichii*.

Æstivation. 48. The way in which the parts of the flower are arranged in the bud is called

* The term *ligulate* is sometimes used in this sense but it also means *furnished with a ligule*.

*aestivation.* The æstivation of the sepals and petals is:—

*crumpled*, when they are irregularly folded;

*valvate*, when their margins are in contact and there is no overlapping. When the margins, besides being in contact, are turned straight inwards it is *valvate-induplicate*, and when the margins are involute it is *valvate-involute*;

*imbricate*, when their margins overlap and at least one of each whorl has both margins covered;

*contorted*, when every one of the same whorl has one margin covered and one margin uncovered. Assuming that the observer stands outside the whorl and therefore behind the sepals, or petals, as the case may be, when the right-hand margin of each is uncovered they are said to overlap to the right and when the left-hand margin of each is uncovered to overlap to the left.

In addition to overlapping the leaves may be twisted, and this twisting may, or may not, be in the same direction as the overlap.

*plaited*, or *plicate*, when they are in longitudinal folds.

For illustrations see *Figs. 15—19, Plate X.*

Characters of Stamens. 49. As already noted a normal stamen consists of a swollen head (the anther) on a stalk (the filament).

A typical anther consists of two longitudinal halves, or lobes, called *thecae*, each of which, at least when young, contains 2 cells, or chambers. These cells contain the pollen and are called the *pollen-sacs*. When mature the anther opens (*i.e.*, dehisces) and allows the pollen to escape. Each theca commonly opens by a longitudinal slit in such a way that one slit opens at once into both sacs, each theca thus appearing to be one-celled. The two sacs in each theca also are sometimes confluent before dehiscence. In a few cases the anther has only one cell. According to the number of cells it is *uni-*, *bi-*, or *quadri-locular*. The anthers sometimes dehisce by means of small holes (*pores*) and sometimes by valves. That portion of the filament which runs up between the anther-lobes is called the *connective*. The filament is sometimes wanting and then the anther is said to be *sessile*. Sometimes the anther is not developed and such an imperfect stamen is called a *staminodium* or *staminode*.

The stamens are said to be :—

*monadelphous*, when their filaments are all united into a tube ;
*diadelphous*, when in two sets, or bundles ;
*polyadelphous*, when in several sets ;
*syngenesious*, when the anthers are united in a ring ;
*didynamous*, when there are 4 stamens, two of them long and two of them short ;
*tetradynamous*, when there are 6 stamens, 4 of them long and two of them short.

If the stamens are inserted on the petals they are *epipetalous*, and if opposite the petals they are *antipetalous*.

If the stamens are the same number as the sepals and petals, the flower is *isostemonous*, if the stamens are double the number, the flower is *diplostemonous*, and if they are double the number and they do not alternate correctly with the petals, the flower is *obdiplostemonous*.

Stamens which protrude beyond the corolla are said to be *exserted ;* if hidden by the corolla they are *included*.

The anther is said to be :—

*introrse*, when the thecæ are turned inwards towards the centre of the flower, *i.e.* when the thecæ are on that side of the anther which faces the floral axis (*ventral* side) ;
*extrorse*, when the thecæ are turned outwards, facing away from the floral axis, *i.e.* when the thecæ are on that side of the anther which is turned away from the axis (*dorsal* side) ;
*innate*, when the filament appears to be fixed in the centre of the base of the anther, the thecæ not facing inwards or outwards. The anther is also sometimes said to be *basifixed* in this case ;
*adnate*, when the filament appears to run up at the back, or front, of the anther, the thecæ facing inwards, or outwards ;
*versatile*, when it swings freely at the end of the filament ;
*dorsifixed*, when the filament appears to be inserted in the back of the anther ;

The stamens sometimes branch, *e.g.* in the Castor Oil Plant. This is often indicated by the anthers being only one-celled, *i.e.* each is really half a stamen, although in some cases this may be due to the non-development of half the stamen. Anthers

may be provided with bristles, points, spur-or horn-like processes. The connective is also sometimes prolonged into a point beyond the anthers. The filament is usually slender, but varies in shape and is sometimes provided with wings.

Pollen is usually a powdery substance, which, when magnified, is seen to consist of distinct grains. The shape and size of the grains varies in different plants and the surface of the grains may, or may not, be provided with points, knobs, ridges, or other markings. In those plants, the pollen of which is distributed by the wind, the grains are smooth and in others, the pollen of which is distributed by insects, or birds, the grains are usually sticky. In some plants the grains adhere together in masses, the latter being called *pollinia*.

Characters of Pistils.

50. As has been already pointed out, a simple pistil really consists of a single infolded leaf which bears the ovules on its inner margins. Such an ovuliferous pistil-leaf is called a *carpel*. A pistil consisting of one carpel is said to be *simple*, if of more than one carpel it is *compound*. A gynœcium consisting of simple pistils is called *apocarpous*, the carpels being distinct, a gynœcium consisting of a compound pistil is *syncarpous*, the carpels being combined. In a simple pistil the lower surface, or back, of the carpel is represented by the exterior of the pistil, the upper surface, or front, of the carpel forms the interior of the pistil. The united margins of the carpel which bear the ovules look towards the centre of the flower (the axis) and form what is called the *ventral suture* or seam. The opposite ridge, along the back of the pistil, representing the midrib of the carpel, forms the *dorsal suture*. In a compound pistil the carpels may be joined by their margins only, or these may grow inwards and be united in the centre of the pistil. In the former case the pistil is one-celled and in the latter it is divided by partitions called *dissepiments* into several cells, there being as a rule as many cells as there are carpels. (Sometimes this is not the case, there being so-called false-partitions which grow in from the back of the carpels.)

The surface on which the ovules are borne, which is often more or less enlarged, is called the *placenta* and the way in which the placentæ are arranged is called the *placentation*. In the case of a compound pistil in which the carpels cohere by their margins only, the placentæ are on the walls of the pistil and the placentation is called *parietal*; when the margins are brought together and cohere in the axis of the pistil, the placentæ are in the inner angles of the cells, and the placenta-

tion is called *axile.* In some cases the ovules are borne on a central axis which is not connected by dissepiments with the walls of the ovary and the pistil is consequently one-celled. The placentation in such cases is called *free-central.*

As a rule the ovules are borne on the margins of the carpels, but in some cases they are developed all over the internal face of the carpels and the placentation is then called *superficial.*

In a compound pistil the styles may, or may not, be more or less completely combined and the number of styles, or of the divisions of the style, or stigma, often indicates the number of carpels in the pistil.

Owing to one side of the ovary growing more rapidly than another, the style sometimes becomes displaced to one side and appears to arise from the base instead of from the apex of the ovary. Such a style is said to be *gynobasic.*

In some cases the floral receptacle, or torus, is prolonged upwards between the carpels forming a kind of beak to which the ovaries and styles adhere and from which they separate when the fruit ripens. Such a beak is called a *carpophore.*

Characters of Ovules.

51. The rounded out-growths of the carpels which are destined to become the seeds are called ovules. These may be sessile, or they may be provided with a distinct stalk called the *funicle.* A typical ovule consists of a central portion of soft tissue called the *nucellus* which is invested with one or two coats called the *integuments.* The latter do not completely cover in the nucellus, a narrow hole being left at the apex which is called the *micropyle.* The spot from which the integuments originate at the base of the ovule is called the *chalaza.*

Ovules are:—

*erect*, when they rise from the base of the ovary;
*ascending*, when they rise obliquely and are attached near the bottom of the ovary;
*horizontal*, when they are borne on the side of the ovary with their long axis horizontal;
*suspended*, when hanging from the apex of the ovary;
*pendulous*, when hanging obliquely from near the apex of the ovary;
*orthotropous*, when they are straight, with the chalaza and micropyle in one straight line and the chalaza at the apex of the funicle;
*campylotropous*, when the line joining the chalaza and micropyle is curved, the micropyle being brought

round and down near the chalaza. This is caused by one side of the ovule growing faster than the other;

*anatropous*, when they are completelv inverted. The chalaza and the micropyle are in the same straight line, but the upper part of the funicle is apparently adherent to the side of the ovule and forms a ridge called the *raphe*.

Intermediate forms between the above types of course occur.

The spot where the end of the funicle is joined to the ovule is called the *hilum*. When the ripe seed separates from its stalk a scar marks the position of the hilum. In orthotropous and campylotropous ovules the hilum and chalaza coincide; in anatropous ovules they are at opposite ends of the ovule. When the raphe is turned towards the ventral suture of the carpel it is said to be *ventral* and when turned towards the dorsal suture it is *dorsal*. In the nucellus of the ovule there is a large cell called the *embryo-sac*, containing protoplasm which is more or less divided up into separate daughter-cells which may, or may not, be provided with delicate cell-walls. When a ripe pollen-grain reaches the sticky surface of the stigma it germinates. Its outer coat is burst and a long delicate tube is sent out, called the *pollen-tube* into which pass the protoplasmic contents of the pollen-grain. This tube penetrates the tissue of the stigma, and of the style if there is one, usually enters the micropyle and grows until its tip comes in contact with the apex of the embryo-sac. A portion of the protoplasm then passes out from the pollen-tube and unites with a part of the protoplasm in the embryo-sac, and with the fusion of these separate masses of protoplasm into one fertilisation is completed. The lump of protoplasm surrounds itself with a cell-wall, begins to divide, and develops into the so-called *embryo*, or young plant, the ovule now having become the *seed*.

Types of Flowers which may cause Difficulty.

52. Having completed our examination of the parts of the flower a few points which may cause difficulty remain to be noted.

In cases where some of the floral parts are suppressed and not developed, it is not always easy to decide on the true nature of the parts which are present. Thus in the flower of *Clematis*, there are usually 4 conspicuous leaves which look like petals, but which are really sepals, no petals being developed. This is indicated by the fact that rudimentary petals are

sometimes found in their proper place inside the petal-like sepals. The presence of rudiments is thus seen to be of importance, and in doubtful cases a careful comparison of allied plants often helps us to arrive at a decision.

The student should carefully examine the flowers of the following plants as they may cause some difficulty. They are fairly typical of the flowers of a large number of important plants and a few special terms are necessary for their description.

Wheat. (*a*) *Wheat.*—The flowers are in spikelets, and each spikelet contains from 3—5 flowers. Each flower consists of 3 stamens and one pistil with two feathery stigmas, while the perianth is represented by two small hypogynous scales called *lodicules*. Each flower is enclosed between 2 scaly bracts, the outer of which is the *flowering-glume*, while the inner and smaller is the *palea*. Finally outside of all, at the base of the spikelet there are two more dry, scaly bracts, which are called the *outer-glumes*.

The flowers of grasses and bamboos closely resemble this type.

Pea. (*b*) *Common Pea*, *Bean*, *Butea frondosa*, or a *Dalbergia*.—The striking peculiarity here is in the corolla, which is called *papilionaceous* from some supposed resemblance to a butterfly. The two lower anterior petals, which are inside the others, are narrow and fit close together, forming the so-called *keel* (*carina*). Outside the keel are two more narrow petals called the *wings* (*alae*), one on each side of the keel, while finally, outside the wings, there is a large posterior upper petal called the *standard* (*vexillum*). It should also be noted that the filaments of the stamens are more or less united into a tube.

Pine. (*c*) *Pine* (*Pinus*).—The flowers are unisexual. The male flower consists of an axis around which are spirally arranged the numerous scale-like stamens, each stamen bearing two pollen-sacs on its under surface.

The female flower also consists of an axis with numerous spirally-arranged scales which represent the carpels. In the axil of each carpel there are two ovules, lying on another scale called the placental scale. As the fruit ripens, the placental scales become woody and form the familiar Pine *cone*. In this case the flowers are of very simple construction and there is no perianth. Both the stamens and carpels are scale-like, and finally the carpels do not form an enclosed ovary, the ovules merely lying exposed on their upper surfaces. Plants

like this which have their ovules uncovered are called *Gymnosperms* (naked seeded plants), while other plants having their ovules enclosed in an ovary are distinguished as *Angiosperms*. Gymnosperms and Angiosperms.

53. When studying flowers it is convenient to be able to shortly and clearly express on paper the number, relative positions and other characteristics of the floral parts, instead of giving long written descriptions. This can be done by *floral diagrams* and *formulae*. A floral diagram is a plan of the flower in which the position of the various floral parts is indicated by a diagramatic cross-section. To indicate the posterior and anterior sides of the flower, the position of the bract, in the axil of which the flower is borne, must be shown and of the main axis from which the flower springs. Diagrams Floral and Short-hand.

In floral formulæ the following equivalents are used:—

K = calyx (sepals).
C = corolla (petals).
P = perianth.
A = androœcium (stamens).
G = gynœcium (carpels).

The following examples will indicate how formulæ are written:—

$P_{3+3}\ A_{3+3}\ G\ (\bar{3})$.—The flower has a polyphyllous perianth of 6 leaves, in two whorls, each of 3 leaves. There are 6 free stamens, also in two whorls, each of 3, and a syncarpous, inferior gynœcium of 3 carpels. Nothing being said to the contrary the flower is regular.

$K_5\ C_5\ A\infty\ G\infty$.—There are here 5 free sepals and 5 free petals, while the stamens and carpels are too numerous for easy counting. The stamens are free and the gynœcium apocarpous and superior.

$K(5)\uparrow\ C_5\ A(5+5)\ G_1$.—Here there is a gamosepalous calyx of 5 sepals, a zygomorphic corolla of 5 free petals, 10 stamens with their filaments united into a tube and a gynœcium of one superior simple pistil.

## Chapter V.—THE SEED AND FRUIT.

Seed.

54. The normal seed is enveloped in one or two outer coats which correspond to the integuments of the ovule. The outer is usually firm and often hard and is called the *testa*; the inner, when it is present, is thin and delicate and is called the *tegmen*. In some cases there is an additional covering to the seed developed after fertilisation has taken place and which is accordingly not visible on the ovule. This covering usually originates from the funicle or placenta but occasionally also from the micropyle. It is known as an *aril*, *e.g.* the pulp of the Lichi.

Testa, Tegmen Aril.

An outgrowth morphologically similar to an *aril* but which is smaller and may develop from various parts of the seed is called a *caruncle*, or *strophiole*.

The testa of the seed sometimes grows out into a membranous wing, as in *Oroxylum indicum*, see *Fig. 1, Plate XII*, and sometimes is provided with long soft hairs, as in the Cotton plant, these structures aiding the distribution of the seed by wind.

Albuminous Exalbuminous seeds.

Inside the seed-coats we find what is popularly called the *kernel*; this may consist only of the embryo, or the latter may occupy only a portion of it, the remainder of the kernel consisting of the so-called *albumen*. (This is cellular tissue densely packed with food-materials, such as starch, or other substances, which are to serve as food for the young embryo.) In the former case the seed is said to be *exalbuminous* and in the latter *albuminous*. As examples of the former we may take those of the Oak and *Oroxylum indicum*, see *Figs. 1* and *2*, *Plates I* and *XII*, and of the latter the seed of the Pine (*Pinus*).

If the albumen has originated inside the embryo-sac it is called *endosperm*, if it is a part of the tissue of the nucellus it is called *perisperm*.

Albumen may be mealy (when it is easily broken into powder), oily, fleshy, or hard, and even bony. If the outer surface of the albumen is crumpled, or puckered, into narrow folds it is said to be *ruminate*.

Cotyledons Radicle and Plumule of Embryo.

In a well-developed embryo we can distinguish an axis bearing one or more minute leaves; these leaves are called *cotyledons*. That part of the axis situated below the insertion of the cotyledons and from which the primary root of the seedling will be developed is called the *radicle*, while the part of the axis above the cotyledons, which is the end of the

minute shoot, is the *plumule.* The radicle of the embryo always points towards the micropyle. The position of the embryo in the albumen is often characteristic; it may be straight or curved, it may be in the centre of the albumen (*axial*), *eccentric*, or *external* to it as in Grasses. The cotyledons may be placed straight in the seed or variously folded. The cotyledons are:—

*incumbent*, when the radicle is laid along the back of one cotyledon;

*accumbent*, when the radicle is laid along the edge of the cotyledons.

In exalbuminous seeds all the food material is stored in the tissue of the embryo itself, and usually in the cotyledons, which are then thick and fleshy. In other cases the cotyledons are thin and more or less foliaceous. On germination taking place the cotyledons may remain below the ground, as in the Oak, see *Figs. 1* and *2, Plate I*, or be raised up on the growing stem into the light and air, when they usually become green and more or less like ordinary leaves, as in *Oroxylum indicum*, see *Plate XII.* The portion of the stem of a seedling situated below the insertion of the cotyledons is called the *hypocotyl* while that part of the stem lying between the insertion of the cotyledons and that of the first foliage leaf or leaves is the *epicotyl*. Hypocotyl. Epicotyl.

The plants termed Angiosperms, which have been mentioned above, are sub-divided into two great groups known as the *Dicotyledons* and *Monocotyledons* respectively. In the former, which includes most of our important forest species the embryo has typically two opposite cotyledons; in the latter, which includes such plants as the Grasses, Bamboos and Palms, the embryo has typically only one cotyledon. Monocotyledons and Dicotyledons.

55. The mature gynœcium of a flower containing the seeds, with everything which may be joined to it, constitutes the *fruit.* The fruit may consist of a single ripe pistil, in which case it is a *simple* fruit, or of the collection of separate pistils belonging to one flower when it is an *aggregate* fruit, or of the pistils belonging to several flowers united together, when it is a *multiple* fruit, or *infructescence.* If it is provided with a stalk the fruit is said to be *stipitate*, if not, it is *sessile*. Fruit.

The ovary wall becomes the wall of the fruit which is called the *pericarp* and this immediately surrounds the seeds. The position occupied by the embryo with reference to the rest of the fruit is important, and the radicle is said to be

*superior* when it points upwards towards the apex of the fruit and *inferior* when it is directed downwards towards the base. The pericarp may, or may not, be differentiated into definite layers and sometimes as many as 3 can be distinguished, in which case the outer layer is called the *epicarp*, the inner layer the *endocarp*, and the middle layer the *mesocarp*.

In many cases a conspicuous part of the fruit is not developed from the pistils, but from some other part of the flower. Thus in the Strawberry the succulent portion, which forms the greater part of the fruit, is developed from the receptacle, in the Sal the calyx persists and develops into large veined wings, in *Semecarpus Anacardium* the base of the calyx and the receptacle form a conspicuous fleshy base to the fruit, while in the Oak the "cup" of the acorn is formed of bracts. Fruits which, when ripe, open to let the seeds escape are said to be *dehiscent*, those which do not do so are *indehiscent*.

Types of Fruit.

56. The principal types of fruits are :—

A.—Dry and Dehiscent.

(1) *Follicle*, consisting of one carpel and dehiscing by one suture.

(2) *Legume*, consisting of one carpel and dehiscing both by the dorsal and ventral sutures. A legume which is much constricted between the seeds is called a *lomentum*. This often breaks up into one-seeded joints when ripe.

(3) *Capsule*, arising from a compound pistil. May be one or many celled. If a capsule splits open along the dissepiments its dehiscence is *septicidal*, if it splits open through the back of each carpel the dehiscence is *loculicidal*. In both cases the dissepiments separate from the axis. When the dissepiments remain attached to the axis and the valves merely separate from the ends of the dissepiments, as in *Cedrela Toona*, the dehiscence is *septifragal*. In some cases the dehiscence may be partly according to one and partly according to another of these types. In septicidal dehiscence, for instance, if the dissepiments remain attached to the axis, the valves of the capsule may separate from the ends of the dissepiments as in septifragal dehiscence.

(4) *Schizocarp*, arising from a compound pistil and breaking up at maturity into distinct portions, each of which is usually indehiscent and looks like a separate fruit, being called a *coccus*. When a coccus is small and one-seeded it is called a *nutlet*.

### B.—Dry and Indehiscent.

(5) *Nut*, a one-seeded fruit with a hard, dry, pericarp such as the acorn of the Oak.

(6) *Achene*, a one-seeded fruit with a thin, leathery, pericarp.

(7) *Caryopsis*, similar to an achene but the pericarp is closely adherent to the seed, the latter completely filling the cell, whereas in the achene this is not so.

(8) *Samara*, any dry indehiscent fruit which is provided with a wing developed from the pericarp.

### C.—Succulent.

(9) *Berry*, the whole pericarp with the exception of the outer skin (epicarp) is succulent and the seeds are immersed in the pulp.

(10) *Drupe*, the pericarp is differentiated into three layers; the inner, or endocarp, is hard and forms the so-called stone of the fruit, containing the seed, or seeds, and which may be one or more celled. The stone is immersed in the mesocarp which is generally succulent, while the epicarp forms a skin over the mesocarp. The succulent mesocarp is sometimes called the *sarcocarp* and the hard endocarp the *putamen*. In the Mango the portion eaten is the sarcocarp and the endocarp is fibrous.

When a drupe is formed from a gynœcium composed of more than one carpel and the carpels separate and give rise each to a distinct endocarp, so that in the ripe drupe there is more than one stone, each of these stones is called a *pyrene*, as in *Grewia*.

General Terms for describing the Shape of Seeds and Fruit.

57. For describing the shape of fruits, or seeds, the terms which have been noted above in connection with other solid parts of plants may be used, such as fusiform, conical and so on. The terms given for flat surfaces are also employed for describing the outline (as seen in elevation) of solid parts and in addition the following terms are frequently used:

*cylindrical*, elongated with circular cross section.
*spherical*, round;
*globose*, or *spheroidal*, nearly spherical;
*ovoid*, an egg-shaped solid;
*ellipsoid*, an elliptical solid;
*discoid*, circular, and flat, or depressed, in centre;
*compressed*, flattened sideways;

*depressed*, flattened from above ;
*clavate*, club-shaped, thickened above and slender below ;
*turbinate*, top-shaped, ob-conical ;
*pyriform*, pear-shaped ;
*didymous*, slightly 2-lobed ;
*plano-convex*, flat on one side, convex on the other ;
*concavo-convex*, concave on one side, convex on the other ;
*moniliform*, cylindrical, but constricted at intervals like a string of beads ;
*torulose*, slightly moniliform.

## Chapter VI.—GENERAL.

58. According to their *duration* parts of plants are said to be:— Duration of Plant Members.

*fugacious*, falling off very early, almost as soon as they are developed, as the petals of Linseed, or *Reinwardtia trigyna*;

*caducous*, falling off early, *e.g.* petals falling before the flower is fertilized;

*deciduous*, falling at the usual season, *e.g.* petals which fall soon after the fertilization of the flower has taken place;

*persistent*, remaining attached to their support beyond the usual season, *e.g.* petals, or sepals, which remain attached to the fruit.

Parts which wither, but still remain attached to their support, are said to be *marcescent*; parts which persist and increase in size are said to be *accrescent*, such as the sepals of Sal which become enlarged in the fruit.

59. According to their *texture* parts of plants are said to be:— Texture of Plant Members.

*osseous*, bony, *e.g.* the stone of many fruits;

*corneous*, like horn, *e.g.* albumen of Date Palm;

*cartilaginous*, hard and tough like parchment, *e.g.* endocarp of an apple which surrounds the "pips," or seeds.

*chartaceous*, thin, like paper, *e.g.* outer bark of young Birch stems;

*coriaceous*, firm and tough like leather, *e.g.* leaf of Mango;

*sub-coriaceous*, thin and pliable like leaves of *Berchemia floribunda*;

*membranous*, very thin and pliable and somewhat transparent like skin, *e.g.* leaves of *Staphylea Emodi*. If membranous but dry and more or less colourless, the texture is *scarious*;

*paleaceous*, like chaff; scarious but rather stiff;

*fleshy*, thick and soft, like leaves of *Saxifraga ligulata*;

*succulent*, fleshy and juicy, like leaves of *Sedum rosulatum*;

*crustaceous*, hard and brittle, like the rind, or epicarp, of fruit of *Grewia pilosa*.

The texture often varies according to the age of the member, thus leaves which are membranous when young may become coriaceous when mature.

60. The outer skin or surface of plant members is often provided with *prickles*. These Prickles, Hairs, Scales, Glands.

may be distinguished from spines, which are really branches, *i.e.* continuations of the internal tissues, by the fact that they are superficial structures which are easily broken off, and if the bark is stripped off they often come away with it such as do those of Roses and *Rubus*.

A few of the terms used for describing the surface of plant members have been given above and in addition to them the following are in common use :—

*echinate*, with sharp prickles, like a hedgehog;
*verrucose*, or *tuberculate*, warty, with knobby excrescences;
*scabrous*, rough to the touch;
*rugose*, wrinkled.

The surface is also often provided with hairs, or wax, and said to be :—

*glabrous*, if without hairs;
*glabrescent*, almost glabrous, with very few hairs;
*pubescent*, with short, soft, straight hairs; if the hairs are very close together and the surface feels like velvet it is said to be *pilose*, if the hairs are very short and only just perceptible to the touch the surface is *puberulous*;
*hirsute*, pubescent but the hairs are longer and stiffer;
*villous*, shaggy. The hairs are long and weak and not matted;
*tomentose*, densely pubescent, but the hairs are matted and the surface feels softer and more woolly;
*woolly*, tomentose with long hairs, looking like wool;
*floccose*, woolly but the hairs are easily detached, *e.g.* those on the undersurface of leaves of *Pyrus lanata*;
*mealy*, hairs are very short and are easily rubbed off like powder, *e.g.* those on young leaves of *Loranthus pulverulentus*;
*hoary*, or *canescent*, with a greyish-white appearance, due to very minute hairs, too small to be easily distinguished;
*strigose*, with pointed, straight, stiff hairs, lying along the surface;
*silky*, with closely adpressed, soft, fine hairs;
*hispid*, rough with rigid hairs;
*glaucous*, pale bluish green in colour, often due to a thin coating of wax, or so-called *bloom*;
*pruinose*, with a covering of wax, or bloom, *e.g.* branches of *Rubus lasiocarpus*.

The surface is sometimes covered with scales, as in *Elaeagnus*, when it is said to be *lepidote* and in other plants with a sticky secretion when it is said to be *viscid.* Hairs which have branches radiating from one point are called *stellate,* and those with a swollen head excreting a sticky substance are called *glandular, e.g.* the hairs on Roses and on the petiole of *Corylus Colurna.* Structures known as *glands* are often found on the surface of plants. These are more or less prominent, somewhat fleshy, swellings which may, or may not, secrete sticky substances. They are common on the leaf-stalks of *Acacias.* Other kinds of glands have been described in previous paragraphs.

61. The general appearance of a plant is called its *habit.* This depends largely on the stem, whether it is erect, prostrate, climbing and so on, also on whether the stem is branched or not. The simple columnar stem of most Palms is thus readily distinguished from those of the majority of our forest trees which are much branched. Habit also depends on the position, arrangement, and number of the branches, branchlets, and twigs, and on their size and mode of growth. Most trees for instance are bare of branches for some distance from the ground, whereas the stems of shrubs branch close to the ground. *Bombax malabaricum* also is easily recognised in the forest by the fact that its branches are arranged in whorls, or false whorls, see *Fig. 3, Plate XI.* In some trees the branchlets and twigs are thick and few in number, in many of the fleshy Euphorbias and some *Sterculias,* for instance : in others there is a large number of small branchlets and twigs, as in *Hardwickia binata.* In old Deodar the branches are almost horizontal and form terraces of foliage, while in the spruce, from the more or less horizontal branches, the branchlets and twigs hang downwards. In *Ailanthus excelsa* the branches are more or less decumbent. In many trees, the branches or twigs are pendulous or drooping, such as are the terminal shoots of young Deodar, the branchlets of *Anogeissus acuminata* and Anjan, and the branches of *Salix babylonica.* Branches which leave the parent-stem or branch at a wide angle are said to be *divaricate,* such as those of *Combretum ovalifolium,* or *Hamiltonia suaveolens.* On the branches also to a great extent depends the general shape of the crown which is often very characteristic ; in *Albizzia stipulata* the crown is broad and flat-topped, in the Silver Fir it is more or less cylindrical, in the spruce conical, and in the mahua, *Bassia latifolia,* usually rounded. Habit.

Herbs, Trees, Shrubs.

A plant the ærial stem of which is herbaceous and dies down to the ground annually is called a *herb*. There are some plants the stem of which, although it dies down annually, is firm and more or less woody, *e.g. Psoralea corylifolia*. They are also usually classed as herbs. Plants of which the ærial stems, or the greater part of them, persist for more than one year and which are more or less woody* are classed as *shrubs* and *trees* respectively.

A shrub is distinguished from a tree by its smaller size and by the fact that it usually has branches near the base.

According to their size, shrubs andtrees are again usually sub-divided into shrubs, large shrubs, small trees, medium-sized trees, large and very large trees.

An *undershrub* is a plant, of the ærial stem of which a very small portion persists for more than one year. Such a plant is also sometimes said to be *suffruticose, or suffrutescent.*

Large herbs which in size and general appearance resemble true shrubs are usually described as *shrubby, e.g. Sesbania aculeata.*

Climbing plants are termed *herbaceous* if their ærial stems are herbaceous and die down annually, and *woody* if the stems persist for more than one year and are more or less woody.

Annuals, Biennials, Perennials.

A plant, or part of a plant, which only lives for one year is called an *annual*, one which lives for 2 years a *biennial* and one which lives for more than 2 years a *perennial*. Annual plants are always herbs, biennial plants are usually herbs, while a perennial plant may be a herb, shrub, or tree.

The persistent basal portion of the stem of an undershrub and the persistent base of an herbaceous perennial, lying at, or just below, the ground surface, and usually including a small portion of the bases of the ærial stems and the upper thickened portion of the roots and from which new herbaceous stems are annually produced, is called a *stock*, or sometimes, also, a *root-stock*.†

Such root-stocks gradually increase in size and often

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* In a few cases stems which persist for more than one year are distinctly herbaceous, *e.g.* those of the Banana.

† A *rhizome* is also called a root-stock by some botanists.

form large woody masses at, or close below, the ground surface. Examples are :—

*Clerodendron serratum*, *Careya herbacea* and *Combretum nanum.*

A plant which is usually found growing in company with many other plants of the same species is said to be *gregarious*, such as the Sal, many Bamboos and species of *Strobilanthes.* Gregarious and Sporadic Plants.

A plant the individuals of which are widely scattered from each other is *sporadic*.

Although the above distinctions are useful for describing plants it must be understood that here, as elsewhere in morphology, the distinctions are not absolute. Intermediate forms between the types selected are frequently found while in one and the same plant the distinctions cannot always be insisted on. In our Indian forests we have many examples of plants which in some localities are climbers while in others they are erect shrubs, or trees, *e.g. Acacia pennata* and *Carissa spinarum.* Again in some localities *Leea aspera* and *Clerodendron serratum* are perennial herbs, in others undershrubs, and in others large shrubs. Trees which are continually browsed by cattle when young may be prevented from developing normally and be temporarily reduced to shrubs ; in other cases their ærial stems may be more or less completely killed down to the ground annually by fires, or frost, and they may thus be reduced temporarily to undershrubs, or perennial herbs, new shoots being sent up yearly from the stock.

The common arhar, *Cajanus indicus*, is usually an annual, but is sometimes biennial. By artificially preventing the flowering of some plants, also, it has been found possible to convert an annual into a perennial. In annuals the whole plant dies annually, and although in perennials this does not happen, still some portion of the plant usually dies and is shed annually. In many trees and shrubs the leaves do not live for 12 months and the plants are consequently bare of green foliage during some part of the year. They are called *deciduous*, while those plants which have green foliage throughout the year are *evergreen*. In some trees and shrubs small twigs die and are thrown off, as in Pines, *Phyllanthus Emblica* and *Strobilanthes Wallichii*, while in the American Swamp Cypress, *Taxodium distichum*, large branches are periodically shed. Evergreen Deciduous Plants.

# PART II.—ANATOMY.

## Chapter I.—CELLS.

Protoplasm.

62. The bodies of plants and of animals consist primarily of *protoplasm* ; this is a colourless substance, the consistency of which varies with the quantity of water it contains from that of a viscid fluid to that of a firm substance almost like wax. Protoplasm always contains carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus and iron. When heated strongly protoplasm gives off water and then it blackens and gives off ammonia. If heated to red heat an ash is left consisting of small quantities of mineral substances. Protoplasm, however, is a living substance which can be easily killed by too high a temperature, by small quantities of poisons and by other factors. It must not be regarded as a simple chemical compound, and we cannot produce protoplasm artificially by collecting and mixing together all the elements which appear to enter into its composition.

Some plants exist which consist of only a naked mass of protoplasm. Such a mass of living protoplasm is found to be capable of creeping movements, portions of the protoplasm being pushed out which draw the remainder of the protoplasmic body after them. It is also capable of taking up and absorbing bodies containing nourishing materials with which it comes in contact, of building up new protoplasm and thus of growing and increasing in size, of respiration, *i.e.* of absorbing oxygen from the air and giving off carbon dioxide, and finally of throwing off pieces of itself which are capable of an independent existence. In addition to these powers of movement, nutrition, growth, respiration and reproduction, living protoplasm, in common with all living matter, possesses the remarkable characteristic of irritability, *i.e.* it is sensitive to, and capable of re-acting in response to, a stimulus. The quality is most easily recognised in cases where the response is greatly out of proportion to the stimulus. If the leaves of the sensitive plant, *Mimosa pudica*, are lightly touched, the leaflets and pinnae all close together and the whole leaf sinks downwards. In this case contact with another body has supplied the stimulus to which the living protoplasm has

re-acted or responded in a particular way, the final result of such response being manifested in the obvious movements of the leaf and leaflets.

63. The protoplasm in the majority of plants does not occur in naked masses but surrounds itself with an elastic, membranous wall, of a substance called *cellulose*, inside of which it lives. Such an enclosed piece of protoplasm is called a *cell* and its outer envelope the *cell-wall*. Many plants are known, each of which consists of only a single cell, but the body of the more highly organised plants with which we are chiefly concerned is made up of a multitude of such cells which live together in intimate contact, although every such plant originally began life as a single minute cell. **The Cell.**

64. If a thin section from the growing apex of such a plant is examined with a microscope, it will be found to consist of a number of nearly cubical cells, each of them being provided with a delicate cell-wall and all of them fitting closely together. Each cell is full of protoplasm and contains in the centre a rounded body called the *nucleus* which is separated by a definite boundary from the rest of the protoplasm. If the protoplasm is treated with a suitable stain, the nucleus is seen to consist of a number of fine twisted threads, or filaments, which become more deeply coloured than the rest of the protoplasm. The latter, which fills all the rest of the cell outside the nucleus and which usually contains distinct granules, is distinguished as *cytoplasm*. As such a cell increases in size the protoplasm is no longer able to completely fill its cavity and spaces, the so-called *vacuoles*, arise in the protoplasm which usually occupy the greater part of the mature cell, the protoplasm being confined to a layer around the cell-wall, with perhaps a few connecting threads across the cell cavity. However large the vacuoles may be, there is always a continuous layer of cytoplasm surrounding the nucleus and lining the inside of the cell-wall. The vacuoles contain a watery fluid termed *cell-sap* which contains a variety of substances in solution, some intended as food for the protoplasm and others having been excreted by the protoplasm as waste products. The cell-sap also frequently contains a red, or blue, colouring matter called *anthocyanin*, to which the colour of many flowers, fruits and young leaves is due. The cytoplasm in such a cell is often seen to be in active movement, the latter being indicated by the granules contained in it, which are seen to be carried along by the living pro- **Cell Contents.**

toplasm like grains of sand in a stream. If the living cell examined is in a part of the plant exposed to the light, such as a leaf, it will be found to contain, in addition to the nucleus and cytoplasm, the so-called *chlorophyll corpuscles.* These are green bodies, generally ellipsoidal in shape, consisting of dense protoplasm and which owe their colour to the green pigment called chlorophyll which they contain. This pigment is soluble in alcohol and if leaves are boiled and placed in alcohol the green colour can be extracted in the form of a solution. These chlorophyll corpuscles possess the power of making starch from water and the carbon dioxide of the air under the influence of light. The small starch grains, when formed, are dissolved and go to feed the protoplasm, or to be accumulated and stored in certain cells as reserve food material until wanted. In parts of plants not exposed to light, protoplasmic corpuscles essentially similar to the chlorophyll corpuscles are formed but without the characteristic green pigment and sometimes, as in flowers and fruits, the green pigment is replaced by a red, or yellow, one.

The living contents of the cell thus comprise :—

The Nucleus
,, Cytoplasm
,, Chlorophyll Corpuscles

for all of which, collectively, the general term, protoplasm is commonly employed. Among the non-living substances frequently found in living cells the most important are :—

*Starch grains.*—Large grains are only found in cells where a store of reserve starch is being accumulated. Such grains usually exhibit a distinct stratification, their substance being arranged in layers. They turn blue when treated with a solution of iodine.

*Alcurene* or *Proteid grains.*—These consist chiefly of albuminous substances and turn yellow-brown when treated with a solution of iodine. They frequently contain albumen crystals which can be distinguished from crystals of inorganic substances by the fact that they absorb stains and swell when treated with water. They also usually contain rounded, or crystalline, masses of mineral matter. They are common in seeds.

Albuminous substances are the most complex bodies found in the plant, with the exception of the living protoplasm itself, and they contain carbon, oxygen, hydrogen, nitrogen, sulphur, and phosphorus.

Other substances are tannins, fats, ethereal oils, resin, caoutchouc, and mineral crystals the latter usually consisting of Calcium Oxalate

**Cell Division.** 65. So far as is known at present, every cell originates from a pre-existing cell and this is usually brought about by normal cell-division. The whole cell about to divide increases in size, the filaments contained in the nucleus contract and become converted into a few thick threads of equal length. The nuclear membrane enclosing the nucleus then disappears, while each of the threads divides into two longitudinal halves, the latter separating and passing to opposite ends of the cell. The halves collected at each end again coil up and each mass forms a new nucleus provided with a membrane, while between them the formation of a cell-wall completes the division into 2 cells. In this way an accurate division of the nuclear substance contained in the cell is insured.

**Thickening of the Cell-Wall and Formation of Pits.** 66. The cell-wall is at first very thin, but when the cell has attained its full size the wall is more or less thickened, the thickening substance being applied in layers to the original membrane. Such thickened walls are therefore, as a rule, distinctly stratified. Parts of the original cell-wall, however, usually remain unthickened. Sometimes very small areas are thus left and narrow channels through the thickening layers consequently arise, forming the so-called *pits.* The pit in the wall of one cell is usually continued through the thickening layers of the wall of the adjacent cell, so that the cells are connected as it were by a narrow channel which is, however, blocked in the middle by the membranous primary wall. A *bordered-pit* is a modification of the simple pit, the channel of which is wide in the centre and narrow at the ends, the centre of the original wall which blocks the middle of the channel being thickened and forming the so-called *torus*, exactly facing the narrow entrances to the channel. In this case the thickening layers are built out into a dome, instead of being closely adpressed to the primary wall as is the case with a simple pit. The entrance to the bordered-pit is at the apex of the dome.

In other cases when the greater part of the original wall remains unthickened, the thickening portions take the form of narrow bands which sometimes anastomose and form a network. The cell-wall consists chiefly of cellulose, a carbohydrate which after treatment with sulphuric acid turns an iodine solution blue, but as it thickens it is usually more or less

changed by the addition of various chemical substances and is often converted into wood, *i.e.* is *lignified*, or into cork, *i.e.* is *suberised.* The communication between the living protoplasm of adjacent cells is, however, not cut off by the thickening of the wall, for exceedingly fine connecting threads of protoplasm are found to pass chiefly through the thin membranes of the pits but sometimes also through the thickened wall.

Middle Lamella.

When a cell-wall separating two adjacent cells has become thickened, its central portion which occupies the position of the original primary wall is called the *middle lamella*, and this differs more or less markedly from the rest of the wall. In lignified cell-walls it is, as a rule, more highly lignified than the rest of the wall, and if a piece of wood is treated with a solution, such as nitric acid with chlorate of potash, which is capable of dissolving woody substance (*lignin*), the individual cells which compose the woody mass will be isolated by the dissolution of the middle lamella and the structure of the wood is consequently destroyed. In this case only the outer thickening layers of the walls will persist which consist mainly of cellulose and contain less lignin than the middle lamella. In some cases the latter dissolves easily in boiling water and some cells can thus be dissociated by being placed in hot water.

Shape of Cells.

67. Young cells such as those at the growing points of plants, are at first more or less cubical, or rectangular, in shape, but as they grow older and increase in size, as they do just behind the growing points, they may undergo a great change of form, and may also lose their living protoplasm, in which case they are often termed dead cells, although really they are then only cell cavities bounded by the cell walls.

## Chapter II.—TISSUES.

68. A single cell which continues to grow and divide will result in producing an aggregate of cells all of which are coherent from the time of their origin; such an aggregate of cells which are more or less similar, which grow in the same way and which have similar duties to perform is called a *tissue*. As the cells of a tissue grow older their walls frequently separate somewhat from one another and spaces arise between them which are called *intercellular spaces*. Different Kinds of Tissues and their Elements.

The tissues of plants may be first classified as :—

(A) *Meristematic*, or *embryonic*.—Those consisting of cells still capable of growing and dividing and thus of producing new cells.

(B) *Permanent*.—Those consisting of cells which have completed their growth and have ceased to divide.

The cells of permanent tissues vary greatly in size, shape, thickness of their walls, and in other particulars. They may remain more or less rectangular, or cubical, in shape, and a tissue consisting of such cells is named *parenchyma*. The cell walls are usually thin and the cells usually contain protoplasm. Sometimes the cells have their walls thickened, but the thickening substance is situated mainly at the corners of the cells, in which case the tissue is called *collenchyma*. In other cases the cells become much elongated in proportion to their width and their ends are pointed. They then usually contain no protoplasm but only air and water, while their walls are generally thickened and provided with simple pits. Such cells are called *fibres*. Cells, whether parenchymatous, or fibrous, which have their walls very much thickened and in which the cell-cavity is consequently very small and in some cases almost obliterated, are said to be sclerenchymatous, and together form the tissue known as *sclerenchyma*. Cells similar to fibres but which are somewhat shorter and wider, with blunter ends, are called *tracheids*.

By the absorption of their transverse partitions, also, rows of cells may become converted into long tubes which are termed *vessels*, or *tracheae*. Both vessels and tracheids frequently have typical bordered pits on their walls and they are also distinguished as *annular*, *spiral*, or *reticulate*, when the thickening bands on their walls form distinct rings, spirals, or a net work, respectively. When the bordered pits of a vessel

are transversely elongated and are situated close together, one above the other, the thickened portion of the wall alternating regularly with the pit apertures, they look like the rounds of a ladder and the vessel is then described as *scalariform.*

The essential difference between a vessel and a tracheid consists in the fact that the latter is a single cell and the former is produced by the fusion of several cells. The tracheid corresponds, as it were, to a single joint of a vessel. Vessels, however, frequently attain a much larger diameter than do tracheids and they are often clearly visible to the naked eye as *pores* on the transverse section of a stem. Neither tracheids nor vessels contain protoplasm, they are tubes whose special duty is the conveyance of water from the roots to the leaves. Intermediate forms between these typical elements often occur.

The so-called *sieve-tubes* are formed, like vessels, by the fusion of a number of cells, but in this case the transverse partitions, instead of being completely absorbed, are penetrated by a number of small holes, such perforated partitions being called *sieve-plates.* The walls of sieve-tubes are never lignified and are usually thin, with an interior lining of living protoplasm. They are the principal conductors of organic food substances from the leaves to the places where they are required.

Many plants contain so-called *laticiferous-tubes* or *-vessels.* Sometimes these arise by the continued growth and elongation of a single cell and sometimes by the fusion of several cells, as in ordinary vessels.

Laticiferous tubes are usually branched, their walls have a thin lining of protoplasm and are usually thin, while their sap consists of a milky, usually white, fluid. Such tubes are common in Figs, *Euphorbia,* and many other plants, and their latex often contains valuable caoutchouc and gutta-percha. The so-called *resin-canals* of Conifers are really intercellular spaces into which resin is excreted from the neighbouring cells. The oil *glands* in the leaves of the Orange, Lime and other plants are formed by the disorganisation of a group of cells, the cell walls being absorbed and the cavity so formed being more or less filled with ethereal oil.

Tissue Systems.

69. The tissues of the higher plants are usually classified in three groups, or systems, as follows :—

(1) *Tegumentary Tissue System.*
(2) *Vascular Bundle Tissue System.*
(3) *Fundamental Tissue System.*

**Tegumentary System.** The Tegumentary System comprises the *epidermis*, or entire outer skin of the plant, which usually consists of a single continuous layer of cells. These fit close together and, in the ærial parts of plants at all events, have their external walls more or less thickened and *cuticularised*, *i.e.* converted into *cutin*, a substance resembling cork but which is more resistant to the action of caustic potash and strong sulphuric acid. When such cuticularised external walls are very thick their outermost layers are more cuticularised than the rest and form the so-called *cuticle*, which can often be detached as a separate membrane from the other thickening layers. The epidermis is also frequently provided with an additional external covering in the shape of deposits of wax, or various forms of hairs, the latter being outgrowths of the epidermal cells. The cells of the epidermis do not usually contain chlorophyll. It

**Vascular Bundle System.** was pointed out, in Part I above, that the firm nerves, to which the venation of the leaves is due, pass into the stem, where they join on to stouter similar strands which are again continued into the root, and also that these strands were called vascular bundles. In some Balsams, the stems of which are more or less transparent, these strands passing down the stem can be seen with the naked eye and in other cases they may often be isolated from young stems which have been allowed to rot in water by carefully washing away the softer tissue. Vascular bundle skeletons of leaves, also, are often naturally produced as the leaves slowly decay. These vascular bundles together constitute the Vascular Bundle Tissue System.

**Fundamental Tissue System.** All tissue which does not belong either to the Tegumentary or Vascular Bundle System is classed as Fundamental, and consists usually of parenchyma, but also often contains collenchyma and sclerenchyma.

**Structure of Vascular Bundles.** 70. A vascular bundle consists of two portions, the *Xylem*, or *Wood* portion and the *Phloem*, or *Bast* portion. The former consists chiefly of vessels and tracheids, or sometimes of tracheids alone, with some parenchyma, while the phloem portion contains sieve-tubes and parenchyma. Fibres may also be present in both xylem and phloem. Most commonly the xylem and phloem are in contact on one side only and the bundle is said to be *collateral*. In the stem the xylem and phloem portions of a collateral bundle are found on the same radius of the stem, the xylem being nearest the centre of the stem and the phloem nearest the circumference. In some cases the xylem has phloem not only on the outside, but also on the inside, the xylem being placed

between two groups of phloem and in this case the bundle is *bi-collateral.* In cases where either the xylem or the phloem is entirely surrounded by the other, the bundles are called *concentric.* In some cases all the cells of a vascular bundle develop into either xylem or phloem elements, but in others certain cells remain meristematic, *i.e.* retain their power of growth and division. In the former case the bundle is said to be *closed* and in the latter *open*, the meristematic tissue being called the *cambium.* On the outside of the vascular bundle sclerenchymatous fibres are usually found, which often form a more or less complete sheath to the bundle.

Development of Vascular Bundles.

71. A vascular bundle does not of course suddenly arise in the plant tissues with all its parts complete, but is developed gradually, like all other parts of the plant, from cells which at first are homogeneous. In the very young plant embryo in the seed the vascular bundles are not yet recognisable. As the embryo develops, however, certain rows of cells grow longer than their neighbours and, dividing tangentially, give rise to strands of narrow elongated cells, which are destined to become the vascular bundles. The form of these cells gradually changes as they complete their growth, some elongate to form fibres and tracheids, the width of others increases to form vessels, their walls become variously thickened and pitted and their chemical composition is altered, many cells lose their protoplasmic contents, while in other cases the cross walls are more or less absorbed to form vessels and sieve-tubes. This differentiation of a collateral vascular bundle proceeds from the exterior of the bundle on both sides inwards and the first formed elements of the xylem and phloem, which are thus in this case the outermost, are called *protoxylem* and *protophloem*, respectively. In the protoxylem annular or spiral vessels or tracheids are found which do not occur in the rest of the xylem.

The cells at the growing apices of the shoots and roots of older plants are also practically homogeneous and meristematic, just as they are in the plant embryo, and it is only at some distance behind the so-called growing points that we find the vascular bundles fully developed.

## Chapter III.—STRUCTURE AND DEVELOPMENT OF PLANT MEMBERS.

72. If the young stem of a Gymnosperm, or Dicotyledon, is cut across after the collateral vascular bundles have become differentiated, the latter will be found to be in a circle around the stem, the xylem of each bundle being nearest the centre of the stem and the phloem nearest the circumference. The fundamental tissue occupying the centre of the stem, inside the circle of vascular bundles, forms the *pith*, while that between the bundles constitutes the primary *medullary rays*. In perennial stems, and sometimes also in annual stems, after the differentiation of the primary vascular bundles, a further process sets in termed secondary growth in thickness. This is accomplished by the activity of the cambium of the vascular bundles which is a layer of elongated, delicate-walled cells, full of protoplasm, situated between the xylem and phloem, and by the formation and growth of a similar thin layer of cambium in the primary medullary rays between the bundles, which, uniting with the cambium of the bundles, forms a complete ring around the stem. From this cambium new cells are continually being formed, through the division of the cambium cells by tangential walls, both on the inside and outside of the ring, towards the centre and circumference of the stem respectively; the former develop into xylem and the latter into phloem elements. The primary medullary rays are thus broken up by the formation of new xylem and phloem elements from the cambium between the bundles. These elements, however, follow a more or less sinuous course longitudinally leaving a net-work of narrow elongated openings which are filled by rows of cells of fundamental tissue, chiefly parenchyma, running horizontally from the centre of the stem towards the circumference. These cells constitute the secondary medullary rays and as the cambium cells opposite these rays continually form new medullary ray cells opposite them, both on the inside and outside of the cambium ring, a medullary ray, once started, is kept open as the stem increases in thickness and extends both through xylem and phloem elements. As the circumference of the stem gradually enlarges, new medullary rays originate from the cambium between those already formed. By means of the medullary rays communication

Stem of Gymnosperms and Dicotyledons.

Medullary Rays.

is insured between all the living cells of the stem. The rays first formed extend from the pith to the circumference, while those arising later originate at some distance from the pith.

Annual Rings.

In plants the growth of which exhibits periods of activity alternating with periods of rest, there is usually a more or less marked difference between the wood formed at the beginning and end of the period of activity respectively. In the former the vessels are often larger, or more numerous, or, in the absence of vessels, the other elements are usually wider and with thinner walls, and the wood of which they constitute a part contrasts strongly with that which it adjoins formed at the end of the previous season's period of activity, the elements of which are denser. More or less obvious concentric rings thus arise in the wood, which are the so-called *annual rings*. What is known as *heart-wood* consists of dead cells, the cavities of which are, as a rule, blocked up by gums, or other substances, and which, being more or less saturated with tannins, is usually of a dark colour.

Heart-Wood

Wood Elements

The wood of Conifers consists almost entirely of tracheids which have bordered pits chiefly on their radial walls, with some parenchyma, and also sometimes with scattered resin ducts.

The wood of Dicotyledons consists of vessels, tracheids, parenchyma, and fibres.

Bast Elements.

The phloem, or bast, of both Gymnosperms and Dicotyledons consists of sieve-tubes, parenchyma, and long, thick-walled, fibres; the latter, unlike the fibres of the wood, usually have their walls very slightly, or not at all, lignified, and they are therefore tough and flexible. It is owing to this fact that the bast of many species is of commercial value for the manufacture of ropes and cordage.

The above elements occur in varying proportions, the wood or bast of a particular species having more of a certain element than that of another species while in some species certain elements may not be represented.

Stem of Monocotyledons.

73. In the young stem of a Monocotyledon the primary collateral vascular bundles, instead of being arranged in a circle, are often irregularly scattered throughout the fundamental tissue of the stem. The xylem of each bundle is turned towards the centre of the stem as before, but the bundles are all closed, *i.e.* no meristematic tissue remains in them to produce secondary growth in thickness. In this case no distinction can be made between the pith and primary medullary rays. In a few Monocotyledons, *e.g.* some Palms, secondary growth in thickness does occur, a cambium ring arising in the fundamental tissue outside the vascular bundles, but this, instead of forming

continuous wood on the inside of the ring, produces only new areas of fundamental tissue with isolated vascular bundles.

**Roots.** 74. In the young roots of Monocotyledons, Dicotyledons, and Gymnosperms the arrangement of the primary vascular bundles is different from that found in the stem. The xylem and phloem strands of each bundle separate from each other as they pass into the root and are there arranged side by side on different radii of the root and the bundles are then said to be *radial.* The xylem strands also become twisted on themselves so that the protoxylem, instead of being internal, as in the stem, is external. Sometimes the xylem strands meet in the centre of the root and sometimes they do not, there then being a central pith. These separate strands of xylem and phloem follow a straight longitudinal course in the root instead of curving as do the bundles of the stem. In the roots of Dicotyledons and Gymnosperms secondary growth in thickness occurs simultaneously with the similar growth in the stem. In the roots cambium layers first appear on the inside of the phloem strands and, extending thence laterally on both sides, they eventually coalesce opposite the xylem strands, and thus form a complete cambium ring. This ring gives rise to xylem elements on the inside and phloem elements on the outside, as in the stem, broad medullary rays being usually formed opposite the primary xylem strands. The wood of an old root is usually more porous than that of the stem but otherwise they very closely resemble each other in the possession of annual rings and other characters. The cambium of the root is a continuation of that of the stem, there thus being an uninterrupted cambial layer throughout the stem and root and their branches.

In those Monocotyledons which exhibit secondary growth a cambial layer may arise in the root outside the primary bundles but it only produces closed vascular bundle strands scattered in fundamental tissue, as in the stem.

**Abnormal Development.** 75. In addition to the typical mode of secondary growth above described, cases of abnormal development are not uncommon among Dicotyledons and Gymnosperms. In *Cocculus laurifolius, Bauhinia Vahlii, Cycas,* and several other plants, the cambium ring first formed ceases to grow after a time and then a second cambium ring arises outside the bast formed by the first. This also ceases to grow after a limited time and a third ring arises, and so on, the stem in consequence exhibiting very characteristic, more or less concentric, bands of wood and soft bark-like tissue, which have been already mentioned on page 18.

In other cases the cambium forms much more wood or bast at certain points than at others, and, on a cross section, radial masses of wood and bast are formed alternating with each other, the cambium forming an undulating layer instead of a circle.

Periderm and Bark.

76. In those Dicotyledons and Gymnosperms in which the interior of the stem is continually increasing in thickness through the activity of the cambium ring, the fundamental tissue and epidermis, which at first surrounded the primary vascular bundles, is subjected to pressure and tension. In some cases the cells composing these tissues continue to grow and divide and thus keeping pace with the internal development are able to persist. This occurs in most annual stems and in perennial stems during the first year of their development and occasionally for a longer period. In the majority of perennial stems, towards the close of the first year's growth, the epidermis being no longer able to withstand the strain becomes ruptured and falls off. Before this happens, however, a layer of cells has been produced close below the epidermis which acts like a secondary cambium and is called the *Phellogen*, or *Cork Cambium*. By the active growth and division of this layer new cells are added both towards the exterior and interior of the stem. The former lose their protoplasm and become converted into cork, forming the so-called *Phellem*, while the latter retain their protoplasm and usually contain chlorophyll, constituting the *Phelloderm*. The term *Periderm* includes the Phellem, Phellogen and Phelloderm. The cork cells of the phellem form an elastic protective covering to the stem which is almost impermeable to air and water and which effectually takes the place of the ruptured epidermis. It is owing to the formation of this layer of cork that the colour of young twigs usually changes from green to some shade of brown, the chlorophyll in the cells of the fundamental tissue beneath it being no longer visible as was the case when these cells were covered by the thin epidermis. In some cases the periderm, instead of originating close below the epidermis, is formed deeper down in the fundamental tissue, and sometimes close to the vascular bundles. In such cases, as all the living cells outside it are prevented from obtaining the supply of water and food necessary for their existence, on account of the impermeable cork layer, they dry up and die, forming the rough outer bark which is sooner or later exfoliated. In some trees, *e.g.* the Birch, the first formed, or primary, phellogen remains active for several years and in some species it persists through the entire life of the tree, new cork cells being added below as the outer ones are

exfoliated. In this way a thick corky bark may be formed. As a rule, however, its activity ceases after a short time and another, or secondary, phellogen arises deeper in the stem beneath the first and nearer the actively growing cambium layer. In this case again all the living cells outside the secondary phellogen die and are added to the dead outer bark just as happens when the primary phellogen develops deep in the fundamental tissue. In this way a number of successive periderms may be formed, succeeding each other at short intervals. It will thus be seen that the outer dead bark may consist of cork cells only or, in addition, of dead elements which originally formed a part of the primary fundamental tissue, or of successive periderms, or even of the phloem developed from the cambium. Taking also the word *cortex*, or *bark*, in the usual sense as including all the tissues outside the cambium ring, it will be seen that this consists of an outer portion of dead elements and an inner part which is largely composed of living cells containing protoplasm. According as the periderm forms a regular circle around the stem, or only arcs of a circle, so do the outer layers of dead bark exfoliate as rings or scales.*

Dead bark which does not exfoliate rapidly becomes deeply cracked and fissured.

In the roots of Dicotyledons and Gymnosperms which exhibit secondary growth the primary phellogen usually originates close to the primary phloem, all the tissue external to it then peeling off, while subsequent phellogens arise as in the stem. In the stems and roots of those Monocotyledons which possess a cambium ring and which therefore increase in thickness, periderm is also formed outside the cambium ring in the way just described only in this case the cambium, instead of producing bast continuously on the outside, gives rise to new fundamental tissue.

Lenticels.

77. At certain points in both roots and stems the phellogen, instead of producing cork cells

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* In this book the word "bark" is used in its ordinary sense and denotes all tissues situated outside the cambium. In some botanical books it is applied in a restricted sense to the dead tissues situated outside the phellogen. For the latter, however, the word *rhytidome* seems preferable.

The word *rhytidome* appears to have been first employed in Indian Botanical literature by W. R. Fisher in his *Morphological Botany* (Roorkee 1888), but it has not as yet been generally adopted by botanists. In that book Mr. Fisher has spelt the word in two ways *rhytiderm* (page 76) and *rhytidome* (page 126). In his *Trees, Shrubs, and Woody Climbers of the Bombay Presidency*, 2nd edition, page x, Mr. W. A. Talbot has adopted the word *rhytidome*. The word is believed to be derived from Greek ρυτις = a wrinkle) and δερμα (= skin, hide) and thus signifies *wrinkled*, or *shrivelled, skin*. ρυτις has already given rise to words which are generally accepted in botanical literature, such as *rytidocarpus* (= wrinkled fruit), so that a better spelling of this useful term would appear to be *rytiderm*.

which fit close together without intercellular spaces, gives rise externally to a number of loosely united cells which often protrude considerably beyond the surface. These areas of loose cork cells are the *lenticels*, and they allow the necessary interchange of gases to take place between the intercellular spaces in the interior of the plant and the outer air.

Shedding of Leaves.

78. When leaves are about to be shed a layer of cork, continuous with the periderm of the stem, is formed across the base of the petiole, which is, however, penetrated by the vascular strands which descend from the leaf. Shortly after its formation a layer of cells, a little distance above it in the petiole, becomes absorbed, resulting in the entire separation of the tissues of the leaf from those of the stem and the leaf accordingly falls off. The cork layer below the surface of the scar now protects the inner tissues of the stem from injury and this protection is completed by the blocking up of the cavities of the vessels and sieve-tubes with gums or cork.

Development of Secondary Members.

79. Young leaves and branches first appear on the stem as minute humps caused by the growth and division of a group of cells situated close below the epidermis. As these cells grow the epidermis increases in area accordingly but not in thickness, and it thus remains as a continuous layer over the leaves and young branches and stems. Young roots, on the other hand, originate deep in the fundamental tissue of the parent root, just outside the vascular bundles, and as they develop they force their way through and rupture the tissue lying between them and the exterior of the root, so that they emerge through slits in the tissue of the parent. Each young root also, as a rule, originates just outside a xylem strand of the parent, and they are therefore found in straight longitudinal rows, there being usually as many rows as there are xylem strands in the parent root. These lateral roots also always first appear at some distance behind the growing apex of the parent root, where the tissues have already become differentiated

Development of the Root. Root-cap.

80. The growing point of a root, unlike that of a stem, is protected by a mass of tissue called the *root-cap* formed by the growth and division of the external layer of cells at the apex. The outer cells of this cap are continually exfoliated while new cells are continually added at the base. The actually elongating portion of a growing root comprises a relatively small area, situated immediately behind the apex, and as this elongates it pushes the root apex, protected by its slippery conical cap, in front of it into the earth like a shield. If the roots of a young

plant, *e.g.* a wheat plant such as is shown in *Plate I, Fig. 3*, are carefully removed from the soil and examined, their lower portions will be found projecting from a mass of soil particles like naked white threads. Closer inspection shows that these soil particles are clinging to a number of minute hairs which look like very fine shining lines. These are the so-called *root-hairs* which attach themselves so firmly to the soil particles that the latter can only with difficulty, if at all, be separated from them. When looked at with a microscope, each of these hairs is seen to be a tubular outgrowth of a single epidermal cell, into which it opens at the base, with a thin cell-wall of cellulose and containing living protoplasm. It is principally by means of these hairs that roots absorb their necessary supplies of water and substances in solution from the soil, the older parts of the roots taking no part in this work of absorption. If these delicate hairs were formed on the portion of the root which is rapidly elongating they would be rubbed off as the root pushes downwards into the soil, and hence the elongating region is destitute of these hairs. The root-hairs as a rule only live for a few days and then die off, so that they are absent from the older parts of the root, but as new hairs are continually being formed behind the elongating region a zone of active living hairs is constantly maintained there. Owing to the strong adhesion of the root-hairs to the soil particles, the root is firmly held in the soil and the elongation of the area immediately behind the apex must drive the tip of the root down into the soil, as it cannot force up the firmly anchored part of the root behind it. To enable the root to obtain as much water and mineral salts as possible from the soil, it is obviously an advantage for it to have a large absorbing surface which shall come in contact with as many soil particles as possible. Accordingly, the tip of the root as it grows downwards, usually follows an irregular spiral course, and the multitudes of root-hairs give it a very large absorbing surface. The root-hairs having obtained all the supplies they can from the soil within their reach die off, while the lateral roots then tap those layers of soil which were beyond the reach of the hairs of their parent root.

Root-hairs.

The upper older portion of the young roots of seedlings frequently exhibits the peculiar property of contracting, or shortening. A pull is thus exercised on both the root and stem, and as the former is strongly anchored the lower portion of the stem is pulled down into the soil and the young plant is thus firmly established. The rooting tips of the branches of *Rubus lasiocarpus* may thus be seen to be drawn into the ground and similar contraction is often seen in the older roots

Shortening of Roots.

of mature plants, especially of those plants which have rosettes of leaves close to the ground. In such plants the short stem increases slightly in length each year and the new leaves arise higher and higher on the stem but, notwithstanding this, the new leaves are always situated close to the ground. Transverse wrinkles, or folds, at the base of the root, where the tissues have shrunk, are often clearly visible where such contraction has taken place.

Structure of Leaves.

81. The leaf is composed of fundamental tissue traversed by vascular bundles and covered by an epidermis, all of which are continuous with the corresponding tissues of the stem. The xylem of each bundle is nearest the upper surface of the leaf and the phloem nearest to the lower surface. The fundamental tissue of the leaf may be uniform, but is usually differentiated into the so-called *palisade tissue*, situated under the upper epidermis, and the *spongy parenchyma*, which extends from the palisade tissue to the lower epidermis. The palisade tissue consists of cylindrical cells, rich in chlorophyll, situated close together, with their long axes perpendicular to the leaf surface. The spongy parenchyma consists of irregularly shaped, often stellate, cells, containing less chlorophyll, and between which there are large intercellular spaces. In the leaf, as in other parts of the ærial shoot of the plant, the cells of the epidermis fit close together except at the spots where the openings, termed *stomata*, occur. These stomata are particularly numerous on the leaves and in the leaves of land plants they are found almost exclusively on the undersurface. A stoma is formed by the division of an epidermal cell into two daughter cells, which then separate from one another by the splitting of the wall between them, an opening into the tissues of the leaf thus being formed. These two cells contain chlorophyll, are sausage-shaped, and are called the *guard-cells*. Immediately below the guard-cells is a large intercellular space which is in communication with the other intercellular spaces of the leaf, so that the internal tissues of the leaf are placed in communication with the air which can thus obtain access to the cells, while the escape of gases and water vapour from the leaf is also provided for. According to the quantity of water in the guard-cells their free walls which adjoin the stomatal opening, approach, or recede from, each other, thus closing, or opening, the stoma. When the guard-cells are turgid and full of water their free walls are drawn apart and the stoma is opened, while if the guard-cells lose water and their walls are no longer tightly stretched, as they are in turgescence, their free walls are pushed together and close the stoma.

# PART III.—PHYSIOLOGY.

## Chapter I.—FUNCTIONS OF PLANTS IN GENERAL.

**General Conditions of Plant Life.**

82. It has been noted in *Part II* that the essential living substance of plants consists of protoplasm and that this protoplasm is capable of doing various kinds of work, of performing various *functions*, such as those of nutrition, respiration, growth, movement and reproduction. See page 68.

Protoplasm can, however, only perform these functions provided that the external conditions are favourable. If no water is available protoplasm at once becomes inactive and may die, while it is easily destroyed by too high or too low a temperature.

The protoplasm contained in the cell from the growth and development of which a Teak tree is ultimately produced must clearly have a very different structure from that contained in the cell which eventually develops into a Sal tree: with the best microscopes at present available, however, no such difference can be detected. Still we must not on that account expect the protoplasm of different plants to always behave in exactly the same way when the external conditions are the same, and, as a matter of fact, we know that different plants have different needs and that the effect of one and the same factor on different plants may be very various. The amount of light, for instance, which is absolutely essential for the healthy development of some plants (*light-demanders*) is often injurious to those plants which live in shady places (*shade bearers*).

In all ordinary green plants, however, a suitable supply of water and mineral salts, a suitable amount of light and heat, as well as of free oxygen and carbon dioxide, are essential for their existence and for the vital activity of their protoplasm.

In Physiology, then, we must consider, on the one hand, the living, irritable, protoplasm, and on the other hand, the non-living factors of the plant's environment which are capable of acting as stimuli to the protoplasm, of inducing it to behave in a certain way and to perform definite work, while, under certain circumstances, they may be able to altogether prevent its activity and even to kill it.

For every such external factor there is in fact for each individual plant a *minimum*, *maximum*, and *optimum*, degree of intensity with reference to its effect on any particular function, the first two being the extremes beyond which the function ceases to be performed and the last being that degree of intensity under the effect of which the protoplasm is best able to exercise the function in question. Green plants, for instance, cannot manufacture their organic carbonaceous food from inorganic materials without light, while if the light is too intense the green chlorophyll, by means of which the manufacture is made possible, is destroyed, so that the manufacture of food is only possible provided that the intensity of the light is suitable. Again if the temperature of the soil falls below a certain minimum, or rises above a certain maximum, the protoplasm in the root-hairs becomes inactive and the roots can no longer provide the plant with the necessary water and salts from the soil.

83. The entire body of some minute green plants which live in water and are called algæ consists of a single cell, such as has been described in *Part II*, in which more or less of the cavity of the cell is occupied by the so-called vacuoles, filled with cell-sap and surrounded by a layer of protoplasm which lines the thin outer wall of cellulose and in which are imbedded the nucleus and chlorophyll corpuscles. Such a minute plant is just as capable of exercising the functions of nutrition, growth, respiration, and reproduction, as are plants the bodies of which consist of enormous numbers of such cells and exhibit an elaborate differentiation into organs. Such a cell, for instance, is able to absorb from the water in which it lives water with traces of mineral

Osmosis. salts in solution. This is effected by *osmosis* or *diosmosis*, a phenomenon by means of which two different liquids, or gases, which are capable of mixing and which are separated by a thin membrane permeable to both of them, are able to diffuse through the membrane until a condition of equilibrium is attained, the liquid or gas on each side of the membrane then being of the same density and composition. If the membrane is more easily permeated by one solution than by the other a larger quantity of the former will pass through it and the latter will consequently increase while the former decreases in volume. The current which flows towards the solution which increases in volume is distinguished as *endosmose* and the current in the opposite direction is *exosmose*. Endosmose usually takes place towards the denser liquid and if a pig's bladder is

filled with a strong solution of common salt, or some other solution denser than water, and is then immersed in pure water the quantity of water passing into the bladder is considerably greater than that of the solution which passes out of it. The more concentrated the solution also, the more rapid is the endosmotic current. The wall of a plant cell, like other organised substances, is capable of imbibing water and swelling. Protoplasm is in this way able to imbibe water to the extent of 90 % of its entire weight, although it then becomes almost fluid. That great pressures may be created by this property of imbibition is shown by the fact that the swelling of wooden wedges, which have been moistened with water, will suffice to split granite rocks, thus indicating how strong this attraction for water is. The walls of living active cells are always saturated with the water they have imbibed and in this condition they are permeable to solids and gases, provided these are in a state of solution, and in this state these substances are able to diosmose freely through the cell walls.

In the living cell, however, another factor besides the cell-wall enters into the case which is able to a certain extent to control and regulate this purely physical phenomenon of diosmosis and that is the living protoplasm which lines the interior of the cell-wall. It by no means follows, for example, that substances which are able to readily pass through the cell-wall will be able to pass through the protoplasmic lining and thus penetrate to the cell-sap. The protoplasm in fact decides what shall, and what shall not, pass respectively from the cell-sap to the exterior of the cell and from the exterior into the cell-sap. Seeing that the protoplasm of one plant differs more or less fundamentally in character from that of another plant and that the protoplasm of each individual thus has its own particular requirements to satisfy, we should naturally expect that the materials absorbed should differ in different cases, and that while one plant takes up large quantities of a particular substance another may take up less, and this is actually the case. Moreover, plants on account of this selective power are able to collect and accumulate large amounts of substances which exist only in very small quantities in their surrounding medium, diffusion from outside continually replacing the small quantities of any particular substance which the plant may absorb from its environment.

84. The controlling power of the living protoplasm is also responsible for the phenomenon called *turgescence*. In the cell-sap of the living alga, for Turgescence.

instance, strong solutions of sugars and other substances exercising a powerful attraction for water are formed by the protoplasm and are held by it in the cell, so that a current of water is drawn rapidly into the cell by endosmosis just as happens in the case of the pig's bladder. Any substances also which are in solution in the water surrounding the cell which are either absent from the cell-sap, or of which a smaller proportion exists in the cell-sap than is present in the surrounding water, will also pass into the cell-sap with the water current, provided that the protoplasm permits them to pass.

Now, although the protoplasm in this way allows a solution of particular materials to pass through its substance into the cell-sap, it does not permit it to filter back again out of the cell, but holds it fast. As water continues to pass into the cell the protoplasmic lining is pressed outwards against the cell-wall which in its turn becomes distended, but which, by its resistance to the pressure, develops a state of tension in the cell. A cell in this state becomes stiff just like a bladder distended by air and is said to be *turgid*, or in a state of *turgescence.*

The young growing leaves and shoots of the higher plants, which consist almost entirely of living cells, each one of which closely resembles our algal cell, are enabled to stand erect and to exhibit considerable rigidity, owing to a number of the cells being turgid and stiff. If a young shoot is cut and kept without water we know that it soon droops and becomes flaccid, the cells composing it having lost water and being no longer able to remain turgid.

Again, if a living cell is brought into contact with a concentrated solution of a substance which has a stronger attraction for water than have the substances contained in the cell-sap water may be drawn out of the cell to such an extent that it is no longer able to remain turgid and the protoplasm becomes inactive and unable to perform its functions. It is on this account that plants are, as a rule, unable to obtain their supplies of water and hence also of dissolved mineral salts from concentrated solutions.

Transpiration.

85. As the mineral salts required as raw food materials must thus enter the living turgid cell as very dilute solutions, in order that the cell may obtain a sufficiency of salts a large quantity of water must continually be got rid of, and the protoplasm, while not allowing the salts which it requires to pass out of the cell and be lost, does

continually permit the water which is in excess of that required to maintain the cell in a state of turgidity to escape. In terrestrial plants this excess water passes off in the form of water-vapour and the phenomenon is termed *transpiration*. Room is thus made in the cell for more water and a continual fresh supply of water and salts is provided for.

**Manufacture of Organic Food Material.** 86. Not only solids, but also gases, in solution are able to enter the cell by osmosis and oxygen and carbon dioxide, which are dissolved in the water surrounding it, are thus able to penetrate into the algal cell. Now, provided that the temperature is suitable and there is sufficient light, the protoplasm is able, by the help of the green chlorophyll, to decompose the water and carbon dioxide contained in the cell and to build up from them an organic carbohydrate which is usually starch, oxygen being given off. This is merely a preliminary process consisting in the building up of a food material which in this case precedes, and is quite independent of, nutrition proper, just as the collection, or cooking, of food may precede actual feeding. Some plants indeed exist which, as we shall see later, can dispense altogether with this preliminary process, although they are composed of living protoplasm which requires feeding just as does that of green plants. Such plants possess no chlorophyll, but by various means they are able to obtain their organic food materials ready-made for them by green plants.

**Respiration and Metabolism.** 87. Living protoplasm, as has been already noticed, *respires*, and plants, like animals, absorb oxygen and give off carbon dioxide. During this process some of the substance of the protoplasm itself appears to be destroyed and broken down into simple compounds, energy being evolved which is in great part dissipated in the form of heat. If therefore the protoplasm is to be maintained alive and enabled to grow, there must be a continual supply of energy available by means of which the very complex protoplasm may be again built up from simpler substances, and further in order that the protoplasm should actually increase in bulk and *grow*, it is obvious that not only must those molecules be replaced which have been destroyed but additional molecules must be constructed. This constant source of fresh energy is, in green plants, supplied by the starch which is being continually manufactured in the chlorophyll corpuscles, and a considerable proportion of which is again being continually broken down into carbon

dioxide and water in respiration. By the breaking up of a molecule of starch energy is liberated and this energy can be employed by the protoplasm in so working on the various mineral salts and other substances in the cell that they, or some of them, are bound together into protoplasm which is thus continually nourished and enabled to grow, while surplus energy is also available for various kinds of work, such as the building up of substances having a strong attraction for water and which are thus able to cause osmotic currents. One and the same substance, however, may be dealt with by the living protoplasm in various ways according to its needs at the time. The starch which has been manufactured in the chlorophyll corpuscles, for instance, may be stored as reserve material and put aside in the form of starch grains, as not being at present needed, it may be converted into cellulose and built into the cell-wall, it may be used as food and built up into protoplasm, or it may be at once broken up in respiration, made to give up its contained energy and converted again into carbon dioxide and water.

When it is considered also that there is a variety of substances in the living cell, both mineral salts, organic substances and gases, and that they all may be dealt with in a variety of ways, it is obvious that the actual processes going on in the cell are exceedingly complex and as a matter of fact they are very little understood. The main fact known about them is, however, that they may all be placed in two great groups — (1) those which consist in the breaking down of complex to simple substances resulting in the liberation of energy, some of which passes off as heat but some of which is always available for work in the cell, and (2) those which consist in the building up of complex from more simple compounds, the ultimate, or end, product being the exceedingly complex protoplasm itself. The latter processes collectively are termed *assimilation*, or *anabolism*, and the former *disassimilation*, or *katabolism*, while all these processes together are termed *metabolism*, which thus means the sum total of all the chemical changes which go on in a living cell. The building up of starch by green plants is thus a process of assimilation. A large number of the substances which are formed in the cell during these various changes are of further use to the plant and can again be used in anabolism, or katabolism, but some are of no further use and these so-called *waste-products* are got rid of by the protoplasm and if possible are *excreted*, *i.e.* passed out of the cell.

88. If now, instead of considering a single cell, we turn our attention to a large plant like a tree which has, as we have already seen, a very complicated structure, we begin to realise the necessity for its variously differentiated parts. If the body of such a plant were composed of an aggregate of thin-walled cells, it is obvious that turgidity alone would not suffice to enable it to stand erect and to resist the enormous strains to which it is subjected. Many cells therefore are deprived of their protoplasm and are converted into thick-walled elements such as fibres, which serve to strengthen and support the plant body. Further, although food materials in solution could diffuse through such a large plant body if it were composed entirely of thin-walled living cells, by osmosis from cell to cell, the currents thus produced would be too slow to satisfy the plant's requirements and hence we find that some cells are converted into conduction pipes, such as the vessels and tracheids, which are able to conduct water and salts rapidly from the roots to the leaves, and the sieve-tubes which conduct the organic food from the leaves to the places where it is required. By means of a system of intercellular spaces, also, which communicate with the outer air, fresh currents of carbon dioxide and oxygen are continually brought into contact with the walls of the living cells, while the water vapour exhaled by the latter is able to quickly pass off into the outer air. That water is actually absorbed by the roots and is given off by the leaves of a highly-organised plant can be easily seen, if the uninjured roots of a young plant are put in an air-tight vessel of water, the whole being placed in a balance. The amount of water then taken up by the roots can be directly measured, while the amount given off by the leaves is given by the loss of weight indicated by the balance.

Conditions of Existence in a Highly-Organised Plant.

If the external conditions remain constant, the amount of water absorbed by the roots is equal to the amount given off by the leaves.

The fact that green plants can grow and develop normally in pure sand, or distilled water, to which certain mineral salts have been added, but which contains no carbon, shows that the carbon required for their organic food is not obtained from the soil. The further fact that starch is actually formed by the green leaves is also easily shown by the following experiment.

Part of a healthy, living leaf on a plant which has been kept in the dark for some hours is covered with a piece of tinfoil,

or other substance, which does not allow light to pass through it, and the plant with its partly covered leaf is then placed in bright sunshine for some hours. The leaf is then cut off and killed by being placed a short time in boiling water. It is then placed in warm alcohol and thus decolourised, the chlorophyll passing into the alcohol in solution. The leaf is then placed in a solution of iodine and finally washed with water, when all parts which had been exposed to the light will be found to have turned blue-black, the colour indicating the presence of starch, the manufacture of which was only possible in those parts where the chlorophyll corpuscles were exposed to the light.

## Chapter II.—FUNCTIONS OF THE HIGHER PLANTS IN DETAIL.

89. It has been already pointed out that the higher plants absorb their supplies of mineral salts and water mainly by means of the root-hairs, each of which is merely the prolongation of a single, living, epidermal cell, provided with a thin wall of cellulose and containing protoplasm, a nucleus, and cell-sap. In all essential details, in fact, it resembles our algal cell except that the green chlorophyll corpuscles are absent. In such a root-hair, therefore, the assimilation of a carbohydrate from inorganic materials cannot take place, but respiration and the absorption of mineral substances in solution can take place, as in the alga. Plant Food Materials.

The chemical constituents of the plant body can be found by analysis. Water in considerable quantities always occurs in a living plant, and in turgid herbaceous plants water may amount to as much as 90% of the entire weight of the plant. About half the dry weight of a plant is made up of carbon.

In *Part II* we have seen that a large number of additional substances enter into the composition of the protoplasm, but other substances also occur and practically all known elements have, at one time or another, been detected in plants.

In order to discover which of all these substances are absolutely essential and in what quantities they are required for the growth and development of various plants, the latter must be grown in pure water to which only known quantities of known substances are added. By such *water-culture* experiments it has been discovered that the following are indispensable for the higher plants:— Essential Substances.

| | |
|---|---|
| Carbon. | Phosphorus. |
| Hydrogen. | Potassium. |
| Oxygen. | Magnesium. |
| Nitrogen. | Calcium. |
| Sulphur. | Iron. |

All of these substances, excepting potassium, magnesium and calcium, are believed to enter into the composition of the protoplasm itself. The calcium appears to be often useful in combining with poisonous substances, *e.g.* oxalic acid, which are then deposited in the plant in a harmless form. Of some of these essential substances only very small quantities are required, but if that small quantity is absent Quantities required.

plant growth and development are impossible. Thus very little iron is required, but unless the necessary minimum is present no chlorophyll is developed. Of these various elements the carbon is obtained from the carbon dioxide of the air, oxygen is obtained partly from the air and partly from water, hydrogen from water and the others are all

Availability.

absorbed in solution by the roots from the soil. Large quantities of these necessary substances, however, may be present in the soil and yet not be available for the plant, because they occur in a form in which the plant can make no use of them. As only substances in solution can penetrate the cell-wall and thus enter the absorbing root-hairs, only such substances as are soluble can be utilised by the plant. Although it appears that some of the higher plants can directly utilise ammonium salts, most of them can only obtain their nitrogen readily when it occurs in the form of nitrates.

Soil—Absorption.

If a solution of organic and inorganic substances is poured on ordinary soil, it will be found that the water which filters through is usually different in composition to that originally added. This is due to the power possessed by the soil of absorbing and retaining various substances, partly on account of chemical combinations taking place, and partly on account of the attraction exercised by the particles of soil. Soils vary considerably with regard to their absorptive power; those containing humus absorb the most and are thus able to store up large quantities of valuable plant food-materials, while sandy soils have very little absorptive power. All substances, however, are not retained with equal vigour; ordinary soils allow the valuable nitrates to filter through and pass away in drainage water, while phosphates, potassium salts and ammonium are usually strongly held. Such absorbed substances can, however, be gradually washed out again if sufficient water is continually added to the soil, so that from the stored substances the dilute solutions required by plants are thus made available in a moist soil.

Power of Plants to obtain Necessary Substances.

Living active root-hairs are continually excreting carbon dioxide as a product of their respiration, and this, passing into the water which surrounds them, aids materially in dissolving and making available for the plant useful substances in the soil. Calcium carbonate, for example, is readily soluble in water containing carbon dioxide and, if a plant is allowed to grow with its roots touching a polished marble plate, the latter will be corroded and etched where the roots have come in contact with it.

Plants, however, differ considerably in their power of extracting their supplies of necessary substances from the soil and those which can tap supplies which are not available for other plants may therefore develop normally on soils where the latter cannot exist. As a general rule, the substances which the higher plants seem to find most difficult to obtain in sufficient quantities are nitrogen, phosphorus, and potassium, and these substances in suitable combinations are, generally speaking, the most valuable manures for field crops, the soil being able to supply a sufficiency of the other substances. Those plants which have special difficulty in obtaining any one of these substances from ordinary soil may therefore, if grown continually on the same ground, be unable after a few years to obtain a sufficient supply for their vigorous development and the yield of agricultural crops may thus sink to $\frac{1}{3}$rd the average produce.

To show how plants vary in this respect, however, it should be mentioned that, according to experience in Europe, although turnips remove large quantities of nitrogen and potassium from the soil, they as a rule only require a manure containing phosphorus, whereas barley and many other field crops usually require an additional supply of nitrogen in the form of manure, if a good crop is to be produced. Again, experiments extending over 50 consecutive years have shown that, when barley is grown on one and the same soil continuously, only nitrogen and phosphorus being given as manure and no potassium, the crop will still be nearly normal and equal to that produced when a full manure of potassium, nitrogen and phosphorus is given. If grown continuously for the same period in the same soil with no manure at all, the crop will sink to nearly $\frac{1}{3}$rd the normal, while if nitrogen is omitted from the manure the yield sinks to less than $\frac{1}{2}$ the normal.

Very little is known regarding the peculiarities of our forest trees in this respect, but it is clear that we have to consider not only the quantity of essential substances contained in the soil and actually removed by the plants, but also the difficulties which each species in nature experiences in availing itself of the substances which are present in the soil, as on this may depend the question of whether, or not, a certain species can be grown continuously for long periods in the same soil.

The root systems of different plants also develop in different layers of soil, and on such facts in great measure depends the theory of rotation of crops and the growing of mixed crops.

Non-Essential Substances.

Many plants are in nature found to take up large quantities of substances which, so far as we can judge from water-culture

experiments, are not essential for their growth and development. These substances, however, may often be indirectly useful; thus silica is often taken up in large quantities and in many plants is deposited in the epidermal cell-walls. This increases the hardness and rigidity of the plant and may aid it considerably in the struggle for existence by rendering it unpalatable to grazing animals. In this way the existence of a plant, in its natural surroundings, may depend on the presence of substances which appear, at first sight, to be unnecessary for its healthy development.

Absorption and Ascent of Wtaer in Plarts.

90. Substances in solution pass into the root-hairs by osmosis as in the case of the algal cell, but, unlike the latter, an individual root-hair does not remain in a continual state of turgidity. The protoplasm of the turgid root-hair after a time appears to relax its resistance to the outward pressure of the water and substances in solution which have accumulated in the cell-sap and this absorbed water with substances in solution consequently filters back out of the cell under a pressure corresponding to that previously exercised by the protoplasm supported by the cell-wall by means of which the state of turgescence was attained. That this pressure can be very considerable is indicated by the fact that, when a young root penetrates a crack in a rock, or masonry wall, as the root increases in size, the pressure exercised by its cells, in their efforts to become turgid and grow, may suffice to split the rock, or wall, as the case may be.

The water, however, which is thus pressed out of the root-hairs, instead of passing out into the soil and thus being lost to the plant, finds its way from cell to cell of the fundamental tissue of the root and eventually passes into the vessels and tracheids of the vascular bundles.

Root-Pressure.

That water with salts in solution is thus pressed by the roots into the vessels and tracheids, and often with considerable force, can be seen by felling a tree when the so-called "sap" is rising, *i.e.* just before the leaves appear and when the roots have commenced to actively absorb water from the soil. The water can be plainly seen to exude from the vessels and tracheids on the cut section and if analysed it is found to contain various substances in solution. By attaching a bent tube containing mercury to the rooted stumps of cut plants the pressure with which this water is pumped up can be measured, and it is found to frequently exceed that of one atmosphere.

Such "bleeding" may continue for several days, or even weeks, and if the roots are kept warm and well supplied with water the quantity of fluid exuded may be large, and often considerably exceeds in volume the total volume of the root system.

That this so-called *root-pressure*, however, in itself does not suffice to explain the ascent of the water current in high trees is shown by the following facts. If the total quantity of water given off by such bleeding stems is measured it is found to be very much less than the amount actually required and given off by the transpiring leaves. Again if an actively transpiring plant in full leaf is cut, the stump, instead of exuding water, will at first actively absorb it, and water placed on the cut section will be taken up by the vessels and tracheids, thus showing that, instead of a positive root-pressure existing in the latter, the existing pressure is less than that of one atmosphere. It has been ascertained also that when transpiration is actively proceeding the water does not occur in continuous columns in the conducting elements, but as short columns, alternating with bubbles of air, and that the pressure in them generally decreases towards the top of the tree.

Now, if for any reason there exists a demand for a particular substance in a certain cell, that substance will continue to be attracted to the cell until the demand is satisfied. If, for instance, owing to the presence of a concentrated solution of a substance having a strong attraction for water, an osmotic current into the cell is created, and further, if this water is driven off in the form of vapour as fast as it enters the cell, the inward current will continue to flow, since the needs of the cell in respect of water remain unchanged. If, on the other hand, the water is allowed to dilute the solution and to continually carry off some of the same to neighbouring cells by exosmosis, a condition of equilibrium will sooner or later be reached, the concentration of the solution in all the cells being the same. Glucose, or grape-sugar, is a soluble substance derived from starch by the addition of a molecule of water, and if we suppose that a dilute solution of glucose is flowing into a cell by osmosis and that on reaching the cell the glucose becomes converted into insoluble starch, which is deposited as starch grains, the inward flow of glucose will continue, the cell's needs in respect of glucose remaining unsatisfied. It is in this way that large quantities of the so-called reserve food-materials are accumulated and stored in certain cells until they are required. Similarly, although currents of water with salts

in solution are continually flowing by osmosis into the living cells of the leaf, each of which, like the algal cell, is busily engaged in the sunlight in manufacturing starch and in building up protoplasm to replace that lost by respiration, yet, as the water which enters is again continually exhaled in transpiration and as the salts which entered with the water are continually being seized on by the protoplasm, made to combine with other substances and built up into protoplasm, or otherwise changed, the attraction exercised by the cells for water and these particular salts in solution remains unchanged, so long as the vital processes mentioned continue actively, and water and salts are in consequence continually withdrawn by the living cells of the leaves from the vessels and tracheids with which they are in contact. In this way a backwardly-acting sucking force is developed which, in some way not yet clearly understood, extends to the roots and causes fresh supplies of water and salts to continually pass into the xylem elements of the vascular bundles from the root-hairs. So much, however, is certain that there is no enormous pressure acting from below which forces the water up to the summit of high trees, and that, although the suction force acting from above is considerable, it also by itself is not sufficient to account for the transpiration current. The most recent researches show that, if the living cells in the wood are killed, the latter soon loses its power of conducting water, and it is thought that the living cells of the medullary rays and wood parenchyma which are in contact with the vessels and tracheids assist in helping on the flow from point to point. It has, however, been ascertained that the water current ascends mainly in the cavities of the vessels and tracheids and not in their walls, and by compressing transpiring shoots and thus diminishing the sectional area of the cavities of their elements the water current can be greatly reduced. It has also been ascertained that the water current ascends in the younger layers of wood and that when heart-wood is present it takes no part in the conduction of water.

Sucking-Force in Leaves.

Transpiration.

91. In large thin leaves the living cells are not shut off from the outer air so effectually as are those in the stem and branches which are soon protected by an outer coat, several layers of cells in thickness, of cork, or other more or less impervious material, and hence, although the outer walls of the epidermal cells of such leaves are usually more or less thickened, a certain quantity of water is continually abstracted from the leaf by evaporation. This process also is largely promoted owing to

the fact that, by means of the numerous stomata and large intercellular spaces in the leaf tissue, the atmospheric air is able to actually come in contact with the thin walls of the living turgid cells in the interior of the leaf which are saturated with water. Room is thus made in these cells for more water which accordingly flows into them from the vessels and tracheids of the leaf vascular strands and continually brings with it a fresh supply of the necessary salts. This evaporation of water from the leaves is called *transpiration*. Within certain limits plants are able to regulate and control the amount of water which shall thus escape from them by closing the stomata, by developing a thick coating of hairs, or other protective covering, from the epidermis, or by other devices, and consequently the quantity of water transpired from a given surface of living leaves is always less than that which would have evaporated from an equal surface of water while a dead leaf, also, loses water by evaporation quicker than a living leaf. With this proviso, however, the factors on which transpiration depends are essentially the same as those which regulate ordinary evaporation, and the amount of water transpired therefore depends on the temperature of, and amount of water contained in, the surrounding air, the presence or absence of air currents, and the area of the surface exposed to evaporation. As a general rule, the rapid removal of water from the actively assimilating cells of the leaf is very necessary to enable them to obtain the necessary quantity of salts they require from the very dilute solution absorbed by the roots. There are, however, obvious cases in which rapid transpiration may be highly injurious, such as when the roots can obtain very little water from a dry soil, and it is essential that plants should be able to regulate this loss of water. That this can only be done within definite limits is indicated by the fact that, during a hot dry day, plants may frequently be seen to droop and become flaccid, the amount of water which has been lost by transpiration, in such cases, being so great that the living cells have been unable to obtain sufficient water from the roots to enable them to remain turgid. They have accordingly become inactive and unable to perform their vital functions. Unless the loss of water has been too great such plants usually recover in the night, owing to the diminished transpiration.

**Regulation of Transpiration.**

In some cases when little or no evaporation can take place, owing to the saturation of the atmosphere, or other cause, plants may become filled with an excess of water and salts in solution which is pumped into them by the active roots.

Water-Pores This excess water is often got rid of by exudation from the ordinary stomata, or from special openings in the leaves called water-pores, such as are found for instance at the tips of the leaves of *Colocasia antiquorum*. Such pores are usually larger than ordinary stomata, and, as their guard-cells contain no living protoplasm and cannot therefore alter their shape, the pores are always open. In the early morning drops of water may often be seen exuding from the leaves of grasses and other plants which have become surcharged with water by the actively absorbing roots during the night. In such cases the escaping water carries with it salts in solution, whereas in transpiration only the water escapes in the form of vapour, the salts remaining behind. As has already been noted, plants can to a certain extent control transpiration by opening or closing their stomata and this is effected mainly by the guard-cells: when the latter are turgid the stomata open and *vice versâ*. The guard-cells become turgid when active transpiration is advantageous, in strong sunlight when plenty of water is available, or when the surrounding air is moist, while they become flaccid and thus close the stomata when active transpiration is likely to be injurious owing to the failure of the water supply, or other cause. In dry localities where roots can obtain very little water from the soil, only those plants can exist which possess very efficient means of preventing rapid transpiration, or which get over the difficulty in some other way. Thus in desert plants the total area of the leaf surface is usually greatly reduced and leaves in many species may be entirely absent, the living, chlorophyll-containing cells being situated in the thick stems and protected by a more or less impervious epidermis, instead of being arranged in large thin leaves provided with numerous stomata.

In many localities the water difficulty only becomes acute during certain seasons of the year and plants are able to exist provided they can complete their development during the period when the soil around their roots is sufficiently moist to supply their needs. Thus in the plains of India, most grasses and herbs complete their development during the rainy season and die down in the hot weather. Deciduous trees also lose their leaves and remain inactive during the seasons when on account of either the low temperature of the soil, or the scarcity of water, the roots would find difficulty in obtaining their supplies. Evergreen trees on the other hand may be able to exist through such seasons owing to the effective checks on transpiration possessed by them in the

way of a reduced leaf area, protective coverings to the leaf, and so on. That such arrangements may be very effective is indicated by experiments carried out in Europe which have shown that the amount of water transpired by evergreen conifers is frequently only $\frac{1}{10}$th of the amount transpired by deciduous dicotyledons, a result which is not surprising when we consider the small area of leaf-surface exposed to the air in the narrow coniferous needles, the strongly thickened cuticle, the stomata sunk below the surface of the needles and thus protected from air-currents, and the presence of sclerenchymatous tissue beneath the epidermis which, as a rule, surrounds and protects the thin-walled chlorophyll-containing parenchyma of such needles. Again, owing to their deep-going root-systems some trees are able to tap a perennial water supply and can thus produce fresh foliage and transpire actively in the hottest, dryest season of the year.

92. That a carbohydrate, which **Assimilation.** is usually starch, is formed in the green leaves of a healthy plant exposed to sunlight, from water and the carbon dioxide of the air has already been pointed out. During this process oxygen is evolved, the volume of oxygen given off being approximately equal to that of the carbon dioxide absorbed. If a green plant is placed in an air-tight jar in an atmosphere from which the carbon dioxide has been removed, no starch is formed in the leaves, thus indicating that the carbon dioxide of the atmosphere is essential for the process. If the cut stem of a green aquatic plant is placed in a cylinder of water in the sunlight, bubbles of gas will be found to escape from the intercellular spaces at the cut surface which can be easily collected and proved to be nearly pure oxygen. By counting the number of bubbles given off per minute, an idea can be formed of the rate at which carbon dioxide is being absorbed and starch manufactured. That light is essential for this assimilation is shown by the fact that no starch is formed in that part of a green leaf which is covered with tinfoil, or otherwise protected from the light. On the other hand it can be shown by experiment that all the **Rays of Light required.** rays of light are not of the same value for this process. If, for instance, a bright solar spectrum is projected on a green leaf for several hours, the leaf then being decolourised with alcohol and treated with a solution of iodine as before described, the blue-black colour, indicating the presence of starch, will be found to be most intense in that part of the leaf which was exposed to the red and orange rays. The same thing can also

be shown by means of the green water plant mentioned in the previous experiment, for if it is placed in a cylinder of red glass the bubbles will be evolved almost as quickly as in ordinary sunlight, whereas in a cylinder of blue glass, which intercepts and cuts off the red and orange rays, the evolution of bubbles almost ceases. If the light which has passed through a solution of chlorophyll is decomposed by a prism, a dark band will be found in the red and orange indicating that these rays have been absorbed by the chlorophyll. The latter, the presence of which is essential for the assimilation of carbon in the higher plants, is thus seen to absorb energy from the sun in the shape of certain rays of light. Assimilation is, however, a vital function performed by the living protoplasm which, in some way which is not yet understood, utilises the energy absorbed by the chlorophyll in decomposing the water and carbon dioxide and in building up from them a carbohydrate, such as starch. The chlorophyll is thus merely a part of the apparatus which the protoplasm employs in this work of assimilation. As might be expected, it will be found that a leaf exposed to the light which has passed through a solution of chlorophyll, or through another green leaf, is unable to assimilate carbon in the way described, the effective light rays being no longer available for the process.

**Light absorbed by chlorophyll.**

**Formation of Starch.**

Among the factors which directly influence assimilation are a suitable supply of iron and carbon dioxide, the temperature, and light, for each of which there is an optimum degree of intensity. It has been already noted that no chlorophyll is formed unless the necessary quantity of iron is available and that without carbon dioxide the assimilation of carbon becomes impossible. The amount of carbon dioxide in the air is as a rule very small, about ·04 % and provided that the light is sufficiently intense assimilation may be increased by increasing the amount of carbon dioxide in the air up to a certain extent. More than 10 % carbon dioxide, however, has a decidedly injurious effect and many plants die if continually exposed to air containing as little as 4 %. Temperature has a marked effect on assimilation, as well as on all other vital functions, and if the temperature is below a certain minimum the protoplasm forms no chlorophyll. In the absence of light assimilation ceases at once, while it increases in proportion to the intensity of the light until the optimum degree of intensity is reached, after which it again decreases. If the intensity of the light continues to increase the chlorophyll is ultimately destroyed.

93. The starch formed in the leaves is not allowed to accumulate there, but is continually being transported to other parts of the plant where it is required for use, or storage. This transport goes on both day and night, but as, during the day, the amount of starch manufactured is considerably in excess of that removed, starch does accumulate in the leaves to a certain extent, which, however, is usually removed during the night. Thus leaves as a rule contain more starch at nightfall than in the early morning. Only those substances which are soluble are able to traverse the cell-walls and they can thus be transported easily and quickly from cell to cell in a plant. Starch, however, is not soluble in water at the ordinary temperature, and hence, for the purposes of transport in the plant, it is converted into a soluble sugar, such as glucose, or maltose, and this is effected by means of the substances called *enzymes*. The latter are chemical substances formed by the protoplasm during metabolism which possess the power of more or less altering various compounds without being themselves effected and many are able to convert insoluble into soluble substances. *Diastase* is a general term for a group of enzymes which are frequently found in plants, some of which can turn starch into glucose, or fruit-sugar, while others turn it into maltose, or cane-sugar. In addition to this power of enabling valuable food materials to be easily transferred from place to place, enzymes are also frequently employed by plants for converting compounds into substances which can be readily assimilated and food materials stored in seeds are often thus made available for assimilation by the young plant. **Enzymes.**

94. All plants, like animals, require to breathe, and, like animals, plants absorb oxygen and give off carbon dioxide, heat being evolved in the process which is known as *respiration*. In the day time respiration is, as a rule, not obvious in green plants growing in the sunlight and which are found to continually enrich the air with oxygen. This is due to the fact that the quantity of oxygen evolved in carbon-assimilation is as a rule much in excess of that required for respiration and that nearly all the carbon dioxide produced during respiration is reassimilated in the cells containing the green chlorophyll. If a green plant, however, is placed in an air-tight jar and covered with black cloth, or otherwise protected from the sunlight, it will be found to absorb oxygen from the air in the jar and to give off an equal volume of carbon dioxide. Again, if a quantity of germinating seeds are placed in an air-tight jar and after **Respiration.**

some hours a lighted taper is introduced into the jar, the taper may be extinguished owing to the exhaustion of the oxygen and the accumulation of carbon dioxide. In such seeds which contain no chlorophyll there is no carbon-assimilation, but respiration, nutrition, and growth are still actively going on at the expense of the food materials stored in the seeds. The fact that seeds can germinate and that seedlings can develop and attain considerable dimensions in the dark, when no carbon-assimilation is possible, clearly shows that nutrition is by no means the same thing as carbon-assimilation. In the case of such seedlings which have developed in the dark, nutrition and growth have taken place at the expense of the organic food materials contained in the seed and the dry weight of such a seedling is found to be actually less than that of the seed from which it sprang. These substances have in fact been lost in respiration, the process which has supplied the energy necessary for nutrition and growth. If on the other hand a seedling is allowed to develop normally in the sunlight, green leaves are produced, carbon is assimilated, and the dry weight of the plant is soon considerably in excess of that of the seed from which it sprang, owing to the fact that more organic substance has been manufactured in the leaves than has been required for respiration.

**Growth.** 95. During the growth of cellular plants the actual enlargement of the cells is effected more by increasing the actual surface-area of the cell-walls than by increasing the substance of the protoplasm, although the latter does of course take place. This enlargement of the cell-walls can only take place provided that the cells are in a state of turgidity and hence a liberal supply of water is essential for the growth of such plants. Like other vital phenomena, growth is only possible within a definite range of temperature. When the latter falls below 0° C, or rises above 40° or 50° C, growth as a rule becomes impossible, while the optimum temperature for growth usually lies between 22° and 37° C.

Light retards growth and plants which have developed in the dark as a rule have unusually long internodes, while their tissues contain more water and their cell-walls are thinner than would have been the case if the plants had been exposed to the sunlight. **Retarded by Light.** As carbon-assimilation is impossible in the dark, even if leaves were developed they would be unable to perform their essential functions and plants which have developed in the dark as a rule form no green chlorophyll. Moreover in such cases material and energy are not

wasted on the construction of leaves of normal shape and size and the leaves which are formed are as a rule unusually small or thin, the plant's efforts being mainly devoted to increasing the length of the stem, with the object of enabling it to reach the sunlight where green leaves can once more assimilate carbon from the air.

Provided that other important factors, such as the amount of available water and the temperature, remain constant, plants, as might be expected, usually grow more at night than in the day.

The rays of light which have most effect on growth are the so-called "chemical rays" which are situated at the blue-violet end of the spectrum. In plants which have developed in a red light, therefore, the retarding effects of light which prevent excessive growth are not seen, and although in such plants chlorophyll is formed, and carbon-assimilation enables them to increase in weight, their growth in other respects resembles that of plants grown in deep shade.

**Plant Movements.**

96. Owing to its remarkable power of irritability the living protoplasm of plants is, as it were, able to perceive the existence of external factors and to regulate its actions accordingly, a fact which is often made manifest by the obvious movements of plant organs.

Thus the protoplasm in the roots and stems of the higher plants is sensitive to the force of gravity and, guided by the direction in which this force acts, it is able to direct the growth of the elongating portions of these organs in such a way that they assume the positions best suited for the performance of their functions. Thus if a healthy seedling is placed with its primary shoot and root in a horizontal position, the growing portions of these organs will be found to curve in such a way that the tip of the root and stem respectively point directly downwards towards the centre of the earth and vertically upwards in a directly contrary direction, growth then being continued in these directions without further curvature. The curvatures to which these movements are due can only take place in those parts of the root and stem which are still growing and they are caused by the unequal growth of the opposite sides of the organ concerned. In the root the upper side grows more rapidly and in the stem the opposite occurs. This phenomenon of movement executed in response to the force of gravity is called *geotropism*. The root which grows towards the centre of the earth, *i.e.* in the direction along which the force of gravity is acting, is said to be *positively geotropic*, while the stem which

**Geotropism.**

grows in the opposite direction, away from the centre of the earth, is *negatively geotropic.* Those parts of plants which grow horizontally, *i.e.* in a direction at right angles to that along which gravity acts, are said to be *dia-geotropic*, such as are often the primary branches of the stem and root. It is also found that if the seedling, after being placed in a horizontal position, is continuously and evenly rotated so that no side of the root or stem is allowed to remain stationary, no geotropic curvature takes place, inasmuch as no sooner does any part of the root or stem receive a stimulus to grow faster than the side opposite to it than it almost immediately receives a contrary stimulus which neutralises it. In these movements, as in the case of those of the leaves of *Mimosa pudica*, we see that the response of the plant is out of proportion to the stimulus applied and the result is quite different to that obtained when the same stimulus is applied to lifeless matter. Thus in this case the shoot moves in a direction exactly opposite to that followed by a lifeless body acted on by gravity, and which falls downwards towards the centre of the earth merely by its own weight. Moreover a primary root growing geotropically downwards is able to penetrate and force its way into mercury which is specifically much heavier than itself, which would not be the case if the root was composed of lifeless substance and was acted on by gravity. The irritability of a plant organ may vary at different periods of its existence, as is shown by the fact of a dia-geotropic lateral root becoming positively geotropic and taking the place of a tap-root which has been cut off, or injured, and the same thing occurs when a lateral branch replaces a damaged leading shoot. This question of the movements of plant organs is complicated by the fact that in nature one and the same organ is frequently exposed to the influence of several factors, or stimuli, to each one of which individually it may be able to respond in a particular way. Thus the movements of such an organ would be the result of the combined influence of all the stimuli affecting it at one and the same time.

Hydrotropism.

Thus roots are also found to be sensitive to the presence of water and are able to regulate their growth with reference to the source of moisture, *i.e.* they are *hydrotropic.* If a primary root is growing in soil with plenty of moisture available on all sides, it will proceed downwards, following the direction suggested by gravity, but if it is situated in a very dry soil, in which moist patches occasionally occur, the root will be found to grow towards the moist areas, it thus being *positively hydrotropic*, irrespective of whether these areas lie directly below it,

or in any other position, the hydrotropism of the root in this case overpowering its geotropism. The ærial roots of some climbing stems are also found to be sensitive to the direction of the rays of light which fall upon them and they respond by growing away from the source of light, *i.e.* they are *negatively heliotropic.* Such roots being also positively hydrotropic and very slightly, if at all, positively geotropic, turn towards the moist dark crevices of their support and not downwards towards the centre of the earth.

**Heliotropism.**

The primary stem, in addition to being negatively geotropic, is also sensitive to the direction of the rays of light falling on it and responds by turning its apex towards the source of light, *i.e.* it is *positively heliotropic.* In this case heliotropism is usually more powerful than geotropism and if the stem is exposed to illumination on one side it will grow obliquely towards the light rather than vertically upwards. Most leaves are also sensitive both to gravity and also to light, they being both dia-geotropic and dia-heliotropic, but their position in nature depends mainly on the direction of the light rays. As a rule they place themselves at right angles to the incident rays of light with their upper surface turned directly towards the source of light. *Plate XIII* for instance shows how the leaves of *Coriaria nepalensis* secure this position on erect and horizontal branches, respectively. In addition to this sensitiveness to the *direction* of the light rays, the floral envelopes and also the foliage leaves of many plants are found to be sensitive to variations in the *intensity* of light and also to variations of temperature. Thus, with a rising temperature and light becoming more intense, many flowers open, while they close with a fall of temperature and a diminished intensity of light. The so-called *sleep-movements* of some foliage leaves are due to the same cause, the leaves in this case assuming a different position at night to that taken up in the day, and as the temperature falls, and the intensity of the light decreases, in the evening, these leaves, or leaflets, are found to close together and to usuallyexpose only their edges to the zenith. In some cases it appears that these movements are of service to the plant in preventing excessive loss of heat by radiation. The so-called night-position may also be taken up in some cases in the daytime, owing to the light being too intense, or the temperature too great.

**Sleep-movements.**

Many tendrils are found to be sensitive to contact with rough solid bodies, as a result of which the side, in contact with the substance grows slower than the opposite side, and the tendril accordingly coils around the obstructing object, (unless the latter is too large) and supports the plant stem.

The movements hitherto considered are those which are brought about chiefly by the unequal growth of opposite sides of the organ concerned and hence they are only possible in parts which are still growing. Those organs which have completed their growth therefore have become fixed in position, and this position isthe one which is onthe whole the best suited for the performance of the functions of each individual organ, having regard to the conditions of its environment. Thus a leaf which is no longer able to move according as the direction of the light rays falling on it changes, takes up a fixed position in which it receives the full benefit of the greatest quantity of the most suitable light rays.

**Movements of Mature Organs.** In addition, however, to the movements which are brought about by a difference in the rate of growth of different parts of organs, plants are also in some cases able to effect the movement of organs after the latter have completed their growth, in response to contact, light, temperature, and other stimuli. In these cases the movement is brought about by an alteration in the turgidity of the cells on opposite sides of the organ concerned. In foliage leaves the pulvinus and pulvinule are organs especially adapted for effecting movements of this description, which can be well seen in the leaves of *Mimosa pudica.* If the cells on the upper side of the pulvinus are turgid, while those on the lower side are flaccid, the leaf will move downwards, and *vice versâ*, the leaf in each case turning on the pulvinus like a hinge. As cells are only capable of becoming turgid when the cell walls are elastic and not rigid, we find that the greater part of the pulvinus consists of parenchymatous cells with non-lignified elastic cell-walls, the vascular strands and strengthening tissue being united in a central strand where it offers least resistance to bending, instead of being distributed nearer the circumference.

**Reproduction. Sexual and Asexual Methods.** 97. There are two modes of reproduction in the Vegetable Kingdom known as the *Asexual*, or *Vegetative*, and the *Sexual*, respectively. In the former a portion of the protoplasm of the parent plant, which may be a single cell, or a multicellular structure such as a bud, separates from the parent and, either at once, or after further growth, constitutes a new individual plant. In sexual reproduction a new individual plant can only be produced after the union of two pieces of protoplasm has taken place which have been developed on different plants, or on different parts of the same plant. Several plants exist which propagate themselves only by the asexual method, others are found to do so only by the sexual

method, while others again employ both methods. In the higher plants asexual reproduction is often brought about by means of stolons and runners, as in the Potato, Strawberry, and *Rubus lasiocarpus.* The young plants developed become separated from, and independent of, their parent by the decay of those portions of the stolons and runners which lie between the young plants and their parent. The same thing apparently often occurs in the case of root-suckers which become independent by the decay of the connecting roots. Asexual reproduction is also effected by means of tubers, bulbs, corms, bulbils, and tuberous roots.

Sexual reproduction in the higher plants is effected by means of seeds. From the fact that two methods of reproduction occur and that some plants which depend only on the asexual method, and some which depend only on the sexual method, are able to exist and successfully maintain themselves in different parts of the earth, we should naturally infer that each method possesses certain advantages. There seems to be no doubt that this is the case and that, under the conditions of existence to which plants are exposed in nature, at one time one method, and at another time the other method, may prove most advantageous. Compared with the structures by means of which asexual reproduction is effected, such as bulbs, corms and tubers, seeds are usually smaller in size, are usually produced in larger numbers and generally possess more efficient means for their wide distribution. In the higher plants, therefore, sexual reproduction tends to result in the establishment of a large number of young plants scattered at a considerable distance both from their parent and from each other. To a great extent, therefore, the roots of each young plant are able to develop in layers of soil which have not been exhausted by the roots of its parent, and each young plant is to a great extent freed from a severe competition for its necessaries of life with other young plants of its own species, which have the same needs and requirements.

With asexual reproduction, on the other hand, it is found that the young plants, although they are not so effectually separated from their parent and each other, grow, at all events at first, more vigorously and attain large dimensions quicker than do those developed from seed. This power of vigorous growth during early youth may often be of vital importance for the existence of the plant, *i.e.* in forest areas which are covered with a heavy growth of grass in which the slow-growing young seedlings of forest trees are often smothered and killed, whereas strong-growing root-suckers may be able to successfully establish themselves.

As regards sexual reproduction, it is clear that in an hermaphrodite flower it is possible (1) for the pistil to be fertilised with pollen developed in the same flower, in which case the flower is said to be *self-fertilised* and (2) for the pistil to be fertilised by pollen developed in another flower occurring on the same plant or in a flower belonging to a separate plant, in which case the flower is said to be *cross-fertilised*. Now, a young plant arising from a seed resulting from the second kind of cross-fertilisation must inherit something from each of its parents, and it therefore tends to vary and to exhibit characters which were not found in the mother-plant. It appears that this tendency to differ from the mother-plant also exists to a certain extent in plants arising from seed produced by self-fertilisation, and all plants raised from seed tend to differ more or less considerably from the mother-plant. In asexual reproduction this is not the case and the young plants are invariably found to resemble their mother-plant very closely. In the case of the young plants arising from seed, a large proportion of which frequently find themselves at a long distance from their mother and exposed to conditions of existence more or less fundamentally different from those under which their mother-plant developed, the possession of slightly different characteristics may obviously be of the utmost use in enabling them to develop successfully. On the other hand considerable variation in the case of asexually produced offspring, established in the immediate neighbourhood of their parent, would as a rule be a disadvantage.

Cross- and Self-Fertilisation.

98. As regards the respective advantages of cross and self-fertilisation, it has been proved by actual experiment in the case of several plants in Europe that cross-fertilisation results in the production of more seeds, which in their turn are able to produce more vigorous plants, than is the case with self-fertilisation. Even if this were universally the case, which has not been proved, it must always be remembered that cross-fertilisation is effected with considerable difficulty and is therefore far more uncertain than self-fertilisation, inasmuch as fewer flowers are likely to be fertilised. It would therefore be quite possible for a plant which uniformly produces a large number of young plants as the result of self-fertilisation to be equally, even if not more, successful in the struggle for existence, in comparison with a plant which habitually produces very few offspring as the result of cross-fertilisation, even if the offspring of the latter were slightly more vigorous than those of the former. It is in fact

probable that, as is the case with sexual and asexual methods, according to the conditions under which plants exist, sometimes self-fertilisation, and sometimes cross-fertilisation, may be most advantageous. That cross-fertilisation, however, is, on the whole, most advantageous in the majority of cases, is indicated by the fact that a very large number of contrivances exist which appear to aim at on the one hand the prevention, or at least the postponement, of self-fertilisation, and on the other hand at facilitating cross-fertilisation.

**Anemophilous, Entomophilous, Ornithophilous, Plants.**

99. For the transference of pollen from the stamens to the stigmas the principal agencies employed by plants are wind, insects, and birds. Plants which are pollinated by the wind are called *anemophilous* and usually have small inconspicuous flowers, with no brightly-coloured perianth, and with no sweet nectar or attractive odour. A the pollen is distributed in all directions by the wind, it is usually produced in very large quantities to insure some of it reaching the female organs, as is the case for instance in Pines and Firs. In Grasses wind-pollination is aided by the fact that the large anthers are versatile and swing freely in the wind, while the feathered stigmas offer a large catchment surface for the pollen. Anemophilous plants are also frequently gregarious, such as are Pines and many Grasses.

Plants which are pollinated by insects are termed *entomophilous* and those pollinated by birds are *ornithophilous.* These as a rule characterised by the possession of conspicuously-coloured floral envelopes with often also nectar and attractive scents. The insects, or birds, attracted to the flowers obtain nectar, or pollen, or both, as food and in their visits carry out for the plant the desired transference of some of the pollen to the stigmas.

**Contrivances for facilitating Cross ertilisation.**

100. The chief contrivances by means of which plants endeavour to bring about cross-fertilisation are :—

(1) *The separation of the sexes.*—This is effectually secured in diœcious and monœcious plants and to a certain extent also in polygamous plants. This is also effected by *dichogamy, i.e.* although the stamens and pistil occur in the same flower they mature at different times. Flowers in which anthers mature first are *protandrous,* those in which stigmas mature first and become ready for the pollen before the stamens dehisce are *protogynous.*

(2) *Heterostyly.*—In some plants it is found that all the flowers on some individuals have stamens and styles of different lengths from those in the flowers of other individuals of the same species. These plants and flowers are said to be *heterostyled.* In species of *Primula* the flowers are *dimorphic,* or of two forms. The flowers on some individuals have short styles with the anthers situated above them at the throat of the corolla, and those on other plants have long styles with the stigma at the throat of the corolla and the anthers below them, deep in the corolla tube. Other plants exist which have *trimorphic* flowers, some with long, some with short, and others with medium-sized styles, with the anthers also arranged at corresponding heights in different flowers, the stigma and anthers of the same height never occurring on one and the same plant.

In such plants it is found that full fertility is only obtained when the stigma is fertilised by the pollen taken from anthers standing at a corresponding level (*i.e.* by pollen taken from the flowers of another plant). All other crosses are termed illegitimate and are found to be more or less sterile, *i.e.* very few seeds are produced as a result of them and if seeds are produced there is less chance of healthy plants developing from them than in the case of a legitimate cross. As the anthers and stigmas standing at the same level in different flowers must come in contact with the same part of the bodies of the insects which visit them, cross-fertilisation is more or less frequently insured, while self-fertilisation is not prevented. Several heterostyled plants occur in India, *e.g. Reinwardtia trigyna* and *Woodfordia floribunda.*

(3) *Mechanical arrangements.*—As illustrations of the truly remarkable mechanisms found in various flowers two plants have been selected, *viz. Salvia lanata* and *Berberis Lycium,* both of which are common in Jaunsar. For illustrations to compare with the following accounts see *Plate XIV.*

Fertilisation of Flowers of *Salvia lanata.*

101. In *Salvia lanata* the corolla is divided into two obvious lips, the lower lip forming a convenient landing-place for insects, while the upper, helmet-shaped lip rises above it like a hood. Nectar

is excreted by the yellow disc at the base of the ovary and collects in the corolla tube. The flowers are much visited by bees and a bee alighting on the landing-stage and wishing to get at the nectar has to pass forward under the hooded upper lip of the corolla and it then finds the entrance into the nectar-containing tube effectually blocked by an ingenious piece of mechanism consisting of the two stamens which is shown in *Fig. 1*, dissected from the flower. Each stamen is attached to the corolla by a short filament on which the long connective swings like a lever on its fulcrum. The upper longer arm of the connective is slender and, together with the pollen-bearing anther-lobe which it carries at its apex, is concealed in the hooded upper corolla lip. The lower thickened connective arm is joined to that of the other stamen which is placed side by side with it in the flower, the metamorphosed lower anther-lobes borne at their extremities coalescing to form a little pouch-like structure which effectually blocks the entrance to the corolla-tube, like a trap-door. See *Fig. 2.* The anthers dehisce by a longitudinal slit which directly faces the landing stage. A bee wishing to get at the nectar and pushing against the obstructing door will move the latter upwards and backwards, the path to the nectar thus being opened, while the upper connective arms descend towards the landing stage and bring their pollen-covered anthers down on the bee's back. See *Fig. 3.* So soon as the bee withdraws, the stamens swing back into their former position. The flowers of this plant are protandrous, *i.e.* the anthers mature and begin to shed their pollen before the stigma is ready for pollination. In a young flower the stigma occupies the position shown in *Fig. 4* (*a*), the stigmatic surfaces being close together and well out of the way of an insect entering the flower. As the flower gets older the style becomes depressed towards the landing stage while the stigmatic lobes separate and become recurved, *Fig. 4* (*b*). A bee, before it can enter the flower at all, must first bring its back, which has probably been dusted with the pollen of a separate younger flower, in contact with the stigmatic surface and cross-fertilisation is thus effected.

**Fertilisation of Flowers of *Berberis Lycium*.**

102. In the case of *Berberis Lycium*, if we look at a flower-bud we find the stamens standing erect in the centre of the flower with their anthers close to the stigma, but the anther-valves are then unopened as shown in *Fig. 5* (*a*), *Plate XIV*. As the flower expands and the petals open out the stamens are bent back with them, the back of the filaments being closely adpressed to the upper surface of the petals. As the flower opens, also, the anthers dehisce. During

dehiscence the valves remain attached only at one point at the top of the connective, and, hinged on this point, each valve gradually rises up, pulling out, as it does so, most of the pollen, which remains attached to its inner surface. *Fig. 5* (*b*). Each valve after rising to an almost horizontal position turns its inner surface which is covered with pollen inwards towards the centre of the flower. *Fig. 5* (*b*) *and* (*c*).

In the open flower these pollen-covered valves are protected from the rain and weather by means of the shelter afforded by the curled-in tips of the petals, so that in looking into the expanded flower the valves are hidden from sight. *Fig. 6*. Looking again at the open flower we see that each staminal filament widens out at its base so as to come in contact with the neighbouring filament on each side of it. Also a little above the base of the filament, on each side of it, there is an oval, orange-coloured, gland which excretes nectar, two of these so-called nectaries being situated near the base of each petal on its upper surface. *Figs. 6 and 7*. Each staminal filament fits in closely between two nectaries and, as already noted, lies with its back closely pressed against the surface of the petal. The nectar excreted by the nectaries flows over the base of the filaments and forms a glistening ring around the base of the ovary. The bell-shaped flowers of this plant are either horizontal, or they hang downwards, and the sepals and petals effectually prevent rain from entering the flower and damaging the nectar, or pollen. It will also be noted that as the petals have their tips curled in to protect the pollen they are not so conspicuous as they would be if they were fully expanded, but to compensate for this and to make the flower more noticeable, the three inner sepals are much enlarged and coloured bright yellow. *Fig. 6*. If now the base of one of the filaments in the expanded flower is touched with a pointed instrument such as a thin pencil, the stamen, with a sudden spring, flies up from its sheltering petal and resumes the erect position it occupied in the unexpanded bud. The pollen-covered valves are thus brought into violent contact with the pencil, but when the latter is removed it will be seen that the valves are not near enough to the centre of the flower to actually touch the stigma. *Fig. 8*.

A bee, searching for nectar with its proboscis and touching the irritable base of one of the filaments, will thus cause the stamen to spring inwards and dust with pollen that side of its head which is turned away from the stigma. The insect being struck by the stamen will often fly away at once and after visiting a few flowers its head will be dusted all over with

pollen, so that, on visiting any other flower, it must inevitably rub off some of this pollen on to the edge of the stigmatic disc and may thus effect cross-fertilisation. The flowers of this species are often visited by small ants and beetles which consume both the pollen and the nectar. Such insects only occasionally spring a stamen and then, as they do not leave the flower at once, but continue to crawl about in search of food, they must at all events occasionally bring about the pollination of the stigma with the flower's own pollen. Moreover, as the pollen-covered valves of a sprung stamen are practically on the same level as the stigmatic surface, it seems certain that some of the flower's own pollen must, sometimes at least, reach its stigma. Thus while self-fertilisation is not prevented, more or less frequent cross-fertilisation is insured.

**Cleistogamic Flowers.**

103. It must always be remembered that, although cross-fertilisation may be, and apparently is as a rule, preferable to self-fertilisation, it is easy for a plant to, as it were, over-reach itself, if in endeavouring to secure the former it makes the latter absolutely impossible; for in the event of cross-fertilisation not being effected, which is in many cases a possible contingency, no seeds at all would be formed and sexual reproduction would absolutely fail. Thus many plants appear to find it safest to at all events insure self-fertilisation in the event of the failure of their efforts to secure cross-fertilisation. This is perhaps most clearly seen in plants which, like many violets, possess two kinds of flowers, (1) large conspicuous flowers adapted for cross-fertilisation, and (2) small, inconspicuous closed flowers adapted solely for self-fertilisation (=*cleistogamic flowers*), the latter insuring a supply of seed in the event of the ordinary flowers not being fertilised.

On the other hand there are certain species which trust entirely to cross-fertilisation. The pollen of some of these plants not only fails to effect the fertilisation of its own flower but acts as a poison, and if applied to the stigmas results in the death of the flower. Finally it must be noted that if a stigma has been pollinated with pollen from its own flower, self-fertilisation may be prevented and cross-fertilisation effected, even if the stigma is pollinated after a considerable interval with pollen formed in another flower of the same species, owing to the latter pollen being *prepotent*, *i.e.* able to effect fertilisation quicker than the flower's own pollen.

**Dissemination of Seeds.**

104. To insure the wide distribution of seeds various devices are employed by plants. In

some cases the seed or fruit is provided with outgrowths which tend to make it buoyant and adapted for dispersal by wind, such as the hairs on the seed of *Holarrhena antidysenterica* and the wing of the seed of *Oroxylum indicum* (*Plate XII*). In other cases the seed or fruit is adapted for conveyance by water, such as are the seeds of Sissoo which remain enclosed in the light pod, the latter serving as a float. The wing-like outgrowths also of many seeds and fruits appear to serve equally well for transport by water or wind. The winged Sâl fruit for instance is often carried considerable distances by water. In other cases the seeds are distributed by animals which eat the fruit and excrete the undigested seeds. The seeds of species of *Zizyphus* appear to be widely distributed in this way by jackals. The seeds of species of *Loranthus* are largely distributed by birds which eat the pulp of the fruit and rub off the seeds on the branches when wiping their bills.

Sometimes the seeds are forcibly expelled to a considerable distance by the bursting of the ripe fruit, as in the case of the capsule of species of *Impatiens*.

Finally, fruits, and rarely also the seeds, may be provided with spines, hooks, or bristles, by means of which they adhere to clothing, the hair or fur of animals, etc., and are thus carried long distances.

# PART IV.—CLASSIFICATION.

## Chapter I.—DEFINITIONS AND EXPLANATIONS.

Necessity for Classification.

105. The fact that there are numerous distinct kinds of plants has been recognised from very early days, and the uneducated native of our forests has required no botanical training to teach him, for instance, that the Sâl tree (*Shorea robusta*) is distinct from the Sain (*Terminalia tomentosa*) or to enable him to recognise these two kinds, or *species*, of tree in the forest. In early days, when the total number of plants known to any single individual was insignificant the want of an elaborate system of classification was not felt, for one could readily acquire and retain in the memory an intimate knowledge of the characteristics of the known plants, which explains how it is that the aboriginal is often found to be well acquainted with, and able to recognise at sight, the majority of the plants growing in the jungle near his village. It, however, soon became evident that, if any individual desired to considerably extend his knowledge of plants and to be able to become quickly acquainted with those of foreign countries, some system of classification was essential, under which all plants could be shortly and concisely described (only essential points of difference being noted) and grouped in such a way as would enable one to quickly refer to its group any plant, where its brief description and correct name would then be obtained. Once the botanical name of a plant has been ascertained, all the information that has ever been placed on record regarding it can then be obtained by referring to the necessary books. Botanical classification thus aims at placing all plants in groups under groups, according to their resemblances, the smallest groups being combined to form larger groups and the latter again formed into still larger groups and so on, the plants included in the smallest of these groups being all very much alike, while those included in the largest groups have fewer points of resemblance. The peculiarities which enable us to distinguish one plant from another are called *characters*.

In a *Flora*, therefore, which is a book containing the descriptions of all the plants of any given country or district, the essential characters which enable us to distinguish the plants

in any one of the largest groups from those in all the others are first given; then under each of the largest groups follow the essential characters distinguishing the next lower plant groups from one another and so on, so that, if we compare the characters of any given plant with those given in the Flora, we are led quickly on from group to group until ultimately we arrive at the smallest group and the correct name of our plant, without wasting time or getting confused in reading and comparing long descriptions of unimportant characters.

**Natural and Artificial Systems of Classification.**

106. It has been recognised from a very early period that "like begets like," that, with plants as with animals, the offspring resemble their parents, and hence, also, it has been accepted as a fact from early times that all organisms which closely resemble each other must be nearly related.

When botanical classification was commenced, it became necessary, first, to analyse and clearly define the essential points of difference between individual plants, *i.e.* their characters, and, secondly, to group together those plants with similar characters. It was then found that, if only one character was relied on, plants were often placed in entirely different groups, although, as regards all their other characters, they were very much alike and were in consequence held to be very closely related. A system of classification, therefore, which only relied on single characters, regardless as to whether, or not, the plants which were most nearly related were thus kept together, was known as an *Artificial System*, whereas a system, according to which all characters were taken into account and which resulted in placing the most closely allied plants in the same group, was known as the *Natural System*.

The best known example of an artificial system is the so-called "sexual system" of Linnæus. Under this system only the characters of the stamens and the distribution of the sexual organs in different flowers were taken into consideration, and all known plants were accordingly classified under 24 groups. As an instance of the artificial nature of this scheme of classification it may be noted that Class XXI *Monœcia* includes two such distantly related plants as the Maize (*Zea Mays*), a Monocotyledon, and the Oak (*Quercus*), a Dicotyledon.

A good artificial system which does not concern itself with the fact as to whether nearly related plants are, or are not, kept together in the groups which it defines, but which merely refers to isolated and easily recognised characters, often enables us to

quickly assign any given plant to the group where its description is to be found, and thus in many cases facilitates the work of identification, for which reason it is still utilised to some extent in modern Floras in the compilation of keys to the larger natural groups.

Striking characters, however, are often inconstant and by themselves are not always trustworthy guides in classification, while, apart from the fact that reliance on a single character is apt to lead us wrong, it must be remembered that, if we depend on one or two characters only, we are quite unable to classify any plant unless the individual in question exhibits those characters at the particular moment of its life-history when we happen to see it. If, for instance, we rely only on the number of cotyledons for the definition of primary groups and the cotyledons are not to be found on our plant, we are at once brought to a standstill and are unable to proceed with the identification. We are then driven to the conclusion that, as a rule, in botanical classification, an aggregate of characters is of more value than one or two striking points of difference, both in indicating general resemblance, and therefore relationship, and in the work of identification. At the present day, botanists endeavour to make all permanent classification as natural as possible throughout, and hence, before deciding to which group any plant belongs, all characters are as far as possible taken into consideration and we then decide which group it, *on the whole,* appears to resemble most, the plants in any one natural group resembling, in the *sum of their characters,* each other more than any other plant.

**The Unit of Classification.**

107. Although, as has been pointed out above, it has been recognised from a remote period that the offspring of any given plant closely resembles its parents, yet close observation showed that, in reality, no two individual plants were ever exactly alike. If then we accept similarity of form and structure alone as the basis of classification, we must adopt the individual plant as the unit. Since, however, every individual plant has only a limited period of existence and sooner or later dies, such a procedure would lead to no practical results. With the individual as the unit we should, for instance, require an unlimited number of names for all the individuals which now exist or which will arise in the future from existing forms by reproduction; we should only be able to catalogue and describe a very small number of all the individuals ever existing on the earth at one and the same time; while the descriptions,

after the death of the individuals to which they refer, would be useless for the purpose of identifying living plants and would, therefore, be of little value to us or our successors. It has, however, long been recognised that although the immediate offspring of any individual usually differ slightly from their parents and each other, they, on the whole, invariably resemble their parents and each other very closely, and this undoubted fact that, within certain limits, all organisms *breed true*, affords the only basis for a natural history classification which shall be of practical value. By discovering within what limits each different kind of plant breeds true, *i.e.* by determining which characters are always transmitted truly to its immediate offspring, we are able to obtain a unit which, so far as we can see, is permanent, the marks which distinguish the individuals belonging to this unit from all other plants being always transmitted unchanged from parents to offspring through successive generations. Such a unit can consequently be recognised and studied by our successors, while, by only giving a separate name to each such unit instead of to each individual, the number of names which will be required is enormously reduced. Such considerations have led to the selection of the so-called *species* as the unit of classification.

It will be seen also that the morphological characters which are most important in classification are those which are always transmitted unchanged from parents to their offspring and which therefore indicate genetic relationship.

Species, Sub-species, Variety, Race, Genus.

108. With these preliminary remarks the following definitions are now given :—

DEFINITION 1.—*A* SPECIES *is the smallest group of plants existing wild in nature which can be readily distinguished from all other groups owing to the fact that the individuals composing it all possess in common certain well marked characters (=specific characters) by which they can be distinguished from all other plants. The individuals also which compose the species are, when developed normally in a state of nature, always able to transmit their specific characters unchanged to the majority of their immediate offspring.*

DEFINITION 2.—*A* SUB-SPECIES *is a group essentially similar to a species but subordinate to it. The differences separating any two individuals belonging to different sub-species not being so great as those which separate individuals belonging to different species.*

Definition 3.—*A* variety *is a group of plants subordinate to a species. The differences between any two varieties of the same species are not constant,* i.e. *they are not always transmitted unchanged from the parent to the majority of its immediate offspring.*

Definition 4.—*A* race *is a variety of considerable fixity. The characters distinguishing the individuals which compose it from those constituting the rest of the species are frequently* (e.g. *in certain localities or under certain conditions of existence*), *but not always, transmitted from the parent to the majority of its immediate offspring.*

Definition 5.—*A number of species which closely resemble one another with respect to their important morphological characters are combined into a higher group termed a* Genus.

Every species in the same genus bears the same name, known as the *generic name*, while, to distinguish the various species included in a genus, each one is given an additional name known as the *specific name.* The name of every species, therefore, consists of two words. Thus all plants belonging to the oak genus bear the common generic name of *Quercus*, while the various species are distinguished by their specific names, thus we have *Quercus incana*, *Quercus glauca*, and so on. The same specific name cannot be used for more than one species in the same genus, but may, of course, be used in another genus. Nomenclature.

In the majority of modern Floras no distinction is drawn between sub-species, races and varieties, all sub-divisions of the species being indiscriminately termed varieties. Of such varieties those which are held to be most important are given separate names, the *varietal name* following the specific name, thus *Cedrus Libani* var. *Deodara.* Unimportant varieties are merely noted below the description of the species in which they are included and are designated by numbers or letters.

As different botanists have sometimes given different names to one and the same plant and as different plants have sometimes received the same name, it is necessary, in order to avoid confusion, to write after the name of the plant the name, in full or abbreviated, of the author who first gave it that name: thus *Rhus Wallichii* Hook f. means that J. D. Hooker was the botanist who first gave the plant this name. A name of a plant which has been superseded by another, owing to its having been considered incorrect for some reason, is

known as a *synonym*. Thus *Rhus Wallichii* Hook f. *syn R. vernicifera* Brandis means that the plant, the correct name of which is considered to be *R. Wallichii* given by J. D. Hooker, is the same as that which had been also named *R. vernicifera* by Sir Dietrich Brandis. The author, whose name, or abbreviated name, is attached to each species, is the person who first put the plant into the correct genus and who therefore is not necessarily the person who was the first to describe the plant or to give it a name.

Natural Order, and Class.

Just as species are combined into genera, so are a number of genera which closely resemble one another in their important morphological characters combined into larger groups known as NATURAL ORDERS, and the latter are similarly combined into still higher groups termed CLASSES.

Principal Natural Groups of Plants.

109. The principal groups of plants therefore which are the most frequently met with, and which form the groundwork of all systems of classification are as follows, commencing with the largest :—

Class
 Order
  Genus
   Species
    Variety

These groups, however, are not sufficient to indicate all the degrees of resemblance which are found to exist, and hence they are often sub-divided, while additional groups are also, if necessary, created. The following is a list of the names most frequently employed for such sub-divisions of the Vegetable Kingdom, given in sequence commencing with the largest. It must, however, be noted that several of these terms have been applied to groups of somewhat different value by different botanists :—

Sub-Kingdom
 Division
  Class
   Sub-class
    Series
     Cohort
      Order*
       Sub-order

* According to the Rules adopted by the International Botanical Congress, held at Vienna in 1905, the groups usually known hitherto in English literature as *cohort* and *order* respectively should be designated *order* and *family*.

Tribe<br>
  Genus<br>
    Section<br>
      Species<br>
        Sub-species<br>
          Race<br>
            Variety.

The main object of classification is to enable us to rapidly become acquainted with the principal groups of plants indigenous in various countries, and it must be remembered that the above definitions refer to groups of plants as they exist growing wild in a state of nature, and that there are many plants which, in the garden, breed true and give the impression of being constant forms and of constituting good species which are not found as wild species in a natural state, owing to their being unable to survive in the struggle for existence or to other causes. Hence, if terms similar to those given above are used for analogous groups of cultivated plants, it should invariably be stated that plants under cultivation are referred to.

**Practical Determination of the Natural Groups.**

110. Proof that a particular group of individuals has descended from another group is not in itself sufficient reason for combining them together as one species, for, in the course of time, the intermediate forms which once united the two groups may have disappeared, causing the two groups to occur in nature as distinct species separated by well-marked and constant differences.

A species is a group of plants which actually exists in nature, the recognition and correct definition of which are independent of the way in which the group originated.

With a few exceptions, the individuals of one and the same species cross readily and produce fertile offspring while individuals belonging to distinct species very frequently do not do so. At the same time fertility cannot be accepted as an infallible criterion of species, for illegitimate unions between the different forms of flowers which occur in one and the same species, in plants with dimorphic and trimorphic flowers, produce very little fertile seed and the plants raised from such seed are sterile *inter se*, just as is frequently the case with the illegitimate unions between distinct species. The male and female forms of some organisms differ widely from each other in many important characters, while an organism may also exhibit an entirely different appearance at different periods

of its life-history. However great such differences might be they would obviously not justify our classing different forms of one and the same organism as distinct species. When defining species, therefore, care must be taken not only to observe what characters are likely to vary in the immediate offspring of one and the same individual plant, but also to note how the characters of the same plant vary at different periods of its life-history. An imperfect knowledge of life-histories has led to mistakes being made in the classification of some fungi, different stages in the life-history of one and the same individual having been sometimes described as entirely distinct species. The words "always able to transmit" in definition 1, while indicating constancy under varying conditions of existence, also imply that, while plants capable of both sexual and asexual reproduction cannot constitute a species if they only transmit their essential characters truly by asexual reproduction, organisms only capable of asexual reproduction are not thereby precluded from forming a true species.

The characters which are used to define species must not only be constant, but, also, in order to facilitate identification, they should, as far as possible, be such as can be easily recognised, and further, to be of use in written descriptions, they must be such as can be easily described in words.

Among the higher flowering plants, with which we are chiefly concerned, characters of the floral structure are as a rule most constant and important and, hence, special attention is paid to them in most Floras, but these, owing to their minuteness, are often difficult to recognise, while flowers are also only available at certain seasons; just as, however, the savage, who pays no attention to such minute characters, is still able to recognise the different trees in the forest, so can also the expert forester, by utilising characters referring to the buds, leaf-scars, kind of bark on young and old stems, the method of branching, the colour of the foliage at different seasons, and others, which, as a rule, are not included in botanical books, owing to their not being easily described in words, to their not being easily recognisable in herbarium specimens, or to their not being sufficiently constant over large areas and in different localities. For this reason, also, a botanical classification based on a single character is not necessarily artificial, for such a character may be correlated with several others, the latter having been omitted from the scheme of classification owing to their being difficult to describe or to distinguish.

In order to determine whether particular groups of plants found wild are to be considered as species, sub-species, races, or varieties, a knowledge of the life-history, as well as of the appearance of the seasonal forms of individual plants, and of the kind and amount of variation which may occur among the immediate offspring of one and the same individual, growing under different conditions, is essential. It is, however, as a rule, impossible to ascertain with certainty the parent of a plant found wild, and very few species have been experimentally cultivated with the object of recording the variation exhibited by them. The systematic botanist, therefore, must rely for his determinations mainly on morphological characters, coupled with his knowledge of the development and variation of the few forms which have been studied.

His conclusions are, consequently, liable to error and to correction in the light of subsequent research, while, in the present state of our knowledge, there is obviously room for considerable difference of opinion as to the kind of characters and the amount of variation which should be held sufficiently important to constitute an inter-specific gap, in consequence of which plants which are regarded by some botanists as distinct species are considered to be varieties by others. The discovery of intermediate forms, also, sometimes leads to two groups of plants, hitherto considered distinct, being combined as one species, it being possible, in such a case, to arrange a complete series of individuals between which there are no marked differences, the slight differences noticed being such as might be expected to occur in the offspring of one individual.

In defining the limits of the larger natural groups and in deciding which species are to be included in the same genus, which genera in the same order, and so on, there is even more room for difference of opinion, and it must be remembered that the difference is not so much as regards facts, such as, for instance, the existence of certain characters, but rather as regards decisions on such questions as to whether the possession of certain characters in common by several plants, may, or may not, be considered to prove a relationship between them, and as to the degree of such relationship. It will thus be seen that the Natural System of Classification is, as yet, by no means perfect, and is liable to modification and alteration as our knowledge extends.

## Chapter II.—PRINCIPAL SUB-DIVISIONS OF THE VEGETABLE KINGDOM.

Primary Sub-Division of the Vegetable Kingdom into Cryptogams and Phanerogams.

111. All plants are first divided into the two great groups, or sub-kingdoms, called respectively *Cryptogams* and *Phanerogams*. The term Cryptogam is derived from two Greek words signifying "hidden marriage" and was originally applied to all plants whose reproductive organs were minute and inconspicuous.

From the absence of what are usually called *flowers*, or structures containing stamens, or pistil, or both, this great group of Cryptogams is sometimes referred to as the one containing "flowerless," or "non-flowering," plants, while the group of Phanerogams is similarly termed that which includes the "flowering" plants.

The essential difference between Cryptogams and Phanerogams, however, consists in the fact that the latter produce true *seeds*, *i.e.* many-celled bodies containing the multicellular embryo or young plant, whereas Cryptogams, in place of seeds, produce *spores* which are unicellular structures. These spores may be developed asexually, or they may arise as the result of a sexual process, the latter being manifest in the mingling together of the protoplasmic contents of distinct cells. When the sexual cells are externally similar, each is termed a *gamete*, when one is smaller and more active than the other, the small active cell is termed the *spermatozoid*, and the large passive cell the egg-cell, or *oosphere*. Spores which are capable of remaining dormant for considerable periods are distinguished from those capable of germinating immediately after their formation by the name of *resting spores*.

Sub-divisions of the Cryptogams.

112. These two great groups are further sub-divided as follows:—

### CRYPTOGAMS.

| | |
|---|---|
| I.—Thallophyta.<br>II.—Bryophyta. | Cellular plants with no true vascular bundles. |
| III.—Pteridophyta. | Vascular plants with true vascular bundles. |

Thallophytes.

Thallophyta.—The plants in this group show no distinct differentiation into stem and leaves and the cellular body

which serves such plants for stem and leaves is called a *thallus*. For our purposes the plants in this group may be sub-divided as follows :—

1. *Algae* . Plants containing chlorophyll.
2. *Bacteria* } Colourless plants without chlorophyll.
3. *Fungi* }

113. *Algae*. This group is of very little importance to the Forest Officer and contains plants of simple structure which live, chiefly, in fresh or salt water, but also on a damp substratum, such as moist soil, the bark of trees in shady forests, etc. Many are coloured green; others are blue-green, brown, red or purple, in such cases some other pigment more or less masking the green chlorophyll. Many are unicellular, or consist of minute filaments, while some of the so-called "seaweeds" are more elaborate in structure, some possessing a root-like attachment organ and with a floating thallus which may attain a length of 800 feet, or even more.

Bacteria. General Account.

114. *Bacteria*. This group includes the smallest of all known plants. They are exceedingly minute and of very simple structure, being unicellular or filamentous, with no indications of any specialised tissue. Many are always present in the air and soil, others live in water, and others in dead or living organic matter. Many are well known in connection with animal diseases and are popularly spoken of as "germs," or "microbes."

Regarding the size of bacteria, we may take, as a fairly typical example, *Bacterium aceti*, the little individual rods of which have a length and breadth of about $\frac{1}{16000}$ of an inch and $\frac{1}{32000}$ of an inch, respectively. Many are capable of active movement by means of exceedingly fine, hair-like processes termed *cilia* or *flagella*.

The presence or absence of these flagella and the shape of the individual cells are important characters for the classification of bacteria. The following forms, for instance, are distinguished by the characters given :—

(*a*) *Cocci*, minute spherical cells.

(*b*) *Bacteria*, rod-like cells with no flagella.

(*c*) *Bacilli*, rod-like cells with flagella scattered over the whole surface of the cell.

(*d*) Spirally curved forms (*Vibrio* closely wound, usually with one polar flagella, *Spirillum* closely wound

with polar tufts of flagella, *Spirochaete* loosely wound, long and filamentous).

The form of one and the same individual, however, may vary considerably at different stages of its life-history or according to the medium in which it is living. The individual bacterial cells are thus sometimes united into chains, or masses of varying form, and owing to the partial dissolution and swelling of the outer layers of the cell walls of the individual cells such masses are often distinctly mucilaginous or gelatinous.

Plants which are thus capable of assuming several different forms are termed *polymorphic*.

So long as conditions are favourable, bacteria grow and multiply very rapidly. Each tiny bacterial cell, whether spherical, rod-shaped or curved, having grown to a certain size, becomes divided by a cell-wall into two equal portions, and, these segments separating from one another, two distinct individuals are formed, each of which then continues to grow until it has attained the normal size, when it also divides into two, and so on. This mode of multiplication by cell-division and the separation of the segments is very characteristic of the bacteria which are in consequence often called the *Fission*—or *Splitting-Fungi* (*Schizomycetes*). When, from the exhaustion of the substratum or some other reason, conditions become unfavourable for growth, the preservation of the plant is insured by the formation of resting spores which can exist for long periods without further development. In the formation of spores the protoplasm of the individual cells rounds itself off and becomes surrounded by a specially thickened membrane, each cell thus becoming a spore. On germination, the protective coat disintegrates and the cell proceeds to grow and form new individuals by division as before. All species are not known to form spores. There is no sexual reproduction and, when spores are formed, no special spore-bearing organ is developed. Many bacteria which can be destroyed by boiling after germination are able to resist high temperatures in the spore condition. Hence boiling a substance or liquid *once* is by no means always sufficient to sterilise it, *i.e.* to absolutely destroy all life in it. The boiling should be repeated several times, an interval of a day being allowed to elapse between each operation, so that some of the spores which might have survived the previous operations may have time to germinate. Direct sunlight is, as a rule, prejudicial to the growth and development of bacteria.

115. Bacteria are of great practical importance for the following reasons :— Practical Importance of Bacteria.

(1) Many species possess the power of more or less decomposing, and altering the composition of, the material from which they obtain their food.

*Bacterium acidi lactici* breaks up milk causing it to become sour.

*Bacterium aceti*, the Vinegar Bacterium, converts alcohol into acetic acid.

*Bacillus vulgaris* is the most common cause of the decomposition of meat.

Such decomposing actions are sometimes spoken of as *decay* or *rotting*, sometimes as *fermentation*, and sometimes, owing to the evolution of evil-smelling gases, as *putrefaction*.

(2) Many species cause very virulent and dangerous animal diseases.

*Bacillus tetani* is found in the soil and causes tetanus.

*Bacillus typhi* causes typhoid fever.

*Vibrio cholerae* causes cholera.

(3) Many species help other plants to obtain the supply of valuable nitrogenous materials which are necessary for their existence.

*Bacillus radicicola* lives in tubercles on the roots of various plants and is able to fix the free nitrogen of the air and to pass it on in a form in which it can be utilised by these plants, this source of nitrogen being otherwise not available for them.

The so-called *Nitrifying Bacteria* live in the soil and convert ammonia to nitrous and nitric acid. Nitrates are thus eventually formed which are the most valuable source of nitrogen for the majority of the higher plants.

It will be seen that, although bacteria are responsible for many of the most virulent animal diseases, they seldom affect other plants injuriously, this being partly due to the difficulty which such minute organisms find in passing through the cell walls of plant tissues.

116. *Fungi*. In this group are included a great variety of plants which are popularly known by various names, such as *moulds, rusts, toadstools, mushrooms*, etc. They are of special importance to the Forester on account of their being responsible for the majority of the most destructive of known plant diseases. Some fungi are Fungi.

very minute and with a structure scarcely more elaborate than that of the bacteria. The common Brewers'-Yeast Plant, for instance, consists of single, oval cells, each cell having a diameter of about $\frac{1}{2000}$ of an inch. It can, however, be at once distinguished from the bacteria by, among other things, its considerably larger size, its peculiar mode of multiplication by what is known as *budding*, or *sprouting*, and by the way in which the spores are formed as will be clear from the life-history given below. The majority of fungi, however, have a much more elaborate structure than that of the simple Yeast Plant, and, although they never show traces of leaves, there is commonly a more or less clear differentiation into root-like and shoot-like portions. Special spore-bearing organs are commonly developed and sexual reproduction is often met with. Many of the simpler forms resemble colourless algæ. Some fungi then are unicellular, but the majority consist of slender, thin-walled, more or less branched filaments, or tubes, called *hyphae*, which are only capable of growing in length at their apices. These hyphæ may possess cross-walls which thus divide them into segments, in which case they are said to be *septate*, or they may be *aseptate*, *i.e.* undivided. The whole vegetative body of the fungus consists of these hyphæ and is called the *mycelium*. This ramifies in the substance from which the fungus derives its nourishment and absorbs the necessary food materials from it and, like the roots of higher plants, usually remains out of sight. Fungi are, therefore, best known by their reproductive organs, which are developed at the surface of the substance on which the fungus is growing, or on aërial branches of the hyphæ. Sometimes the mycelium is superficial and only specially developed short branches of the hyphæ, termed *haustoria*, or suckers, penetrate the substance on which the fungus is growing and absorb the necessary food materials.

The mycelium may consist of a few delicate hyphæ and thus be invisible to the naked eye, or the hyphæ may be collected into dense masses and become visible in the form of papery or skin-like membranes, or thick, felt-like sheets and masses. In some species the slender thin-walled hyphæ are united into bundles, which are provided with a hard, dark-coloured, protective coat. Such strands may sometimes be mistaken for the fine roots of higher plants, which they resemble in general appearance, and they are, in consequence, termed *rhizomorphs*, or root-like structures. Pro-

tected in these strands, the tender hyphæ are able to spread through areas which are unsuitable for their growth and development, the hyphæ being again extruded to absorb nourishment when favourable conditions are met with.

The fungi may be divided into the following groups:— Classification of Fungi.

I.—*Phycomycetes.*
II.—*Ascomycetes.*
III.—*Basidiomycetes.*
IV.—*Ustilaginaceae.*
V.—*Uredinaceae.*

117. *Phycomycetes.* The hyphæ are generally aseptate. Mycelium does not form a compact mass. Sexual reproduction is common. The asexual spores may be developed in spore-cases (=*sporangia*), the protoplasmic contents of which divide up to form the spores, or the end of a hypha may swell up, the swollen tip eventually separating from the hypha to form a spore, which, in such a case, is called a *conidium*, and the portion of the hypha on which it is borne is called a *conidiophore*. Phycomycetes.

*Phytophthora infestans* causes the potato disease. This has been selected as a typical example of this group and its life-history is given in detail in *Part V* below.

Other species of *Phytophthora* and species of *Pythium* are very destructive to seedlings and to palm trees.

118. *Ascomycetes.* Hyphæ are septate. Spores are produced in a special kind of elongated sporangium termed an *ascus*. The number of spores produced in an ascus is almost always definite, usually eight, whereas in a sporangium the number of spores is usually indefinite. In an ascus, also, the protoplasmic contents are not all used up in the formation of the spores, as is the case in a sporangium. These asci may be without any covering, or may be grouped in special structures, called the *ascocarps*, thus forming the *ascus-fruits*. A completely closed ascocarp is called a *cleistothecium*, one with a small aperture at the apex a *perithecium*, and one which is open, saucer-shaped, or hat-shaped, an *apothecium*. Sexual reproduction sometimes occurs. Ascomycetes.

Among the interesting fungi included in this group are the minute, unicellular plants known collectively as the *Yeast Fungi*, or the *Saccharomycetes*, which are capable of causing the alcoholic fermentation of sugar solutions. We know that, if the sweet juice extracted from the sugarcane Yeast Fungi.

is not at once boiled and is left exposed to the air, the process known as fermentation rapidly sets in and that if this is allowed to continue we ultimately obtain in place of the sugar solution one which contains alcohol, carbon dioxide gas being evolved during the process. Yeast Fungi are therefore of great commercial importance in the manufacture of wine from the sugar in grapes, in the preparation of spirit from the sweet-tasting mahua (*Bassia latifolia*) flowers and in the manufacture of wine, beer and spirits, generally. If the minute oval, or spherical, cells of a Yeast Fungus are placed in a suitable nutrient sugar solution they are found to grow and multiply with great rapidity, the peculiar method of multiplication being termed *budding*. The cell wall of the Yeast Plant bulges out and a protuberance is formed which gradually increases in size, the neck connecting it with the mother-cell remaining narrow. A cell-wall is then formed across the narrow neck at the point of union and the swollen protuberance, separating from the mother-cell, becomes a separate cell which then behaves in the same way. When all the sugar has become converted into alcohol and the food material is consequently exhausted, the yeast cells can no longer continue growing and budding and they proceed to form spores. The protoplasm in each cell divides into four little blocks, each block becoming a spore, which is eventually set free by the disintegration of the wall of the mother-cell. Under favourable conditions each of these spores germinates and at once proceeds to grow and bud off new cells as described.

Ferment Organisms.

It has been noted above that bacteria are capable of causing various kinds of fermentation but they do not produce the alcoholic fermentation so characteristic of the Yeasts. Plants, such as bacteria and fungi, which are able to produce fermentation are known as *Ferment Organisms* (sometimes also as Organised Ferments). Such plants appear to owe their power of producing fermentation mainly to the chemical substances known as *Enzymes* which they contain, and which, of course, are not living organisms. The action of the Yeast on the sugar solution will be understood from the following equation :—

$$\underset{\text{(grape sugar)}}{C_6H_{12}O_6} = \underset{\text{(alcohol)}}{2C_2H_6O} + \underset{\text{(carbon dioxide)}}{2CO_2}$$

and it should be noted that, although the Yeast derives its food from the sugar, yet only a very small proportion of the solution is actually utilised as food, the remainder being

decomposed and broken up into simpler compounds. Thus only 5 per cent. of the sugar may be actually used as food while 95 per cent. is reduced to alcohol and carbon dioxide.

Other interesting plants belonging to this group are the species of *Meliola* which form sooty black patches of mould on the leaves of various trees, *e.g.* the Sal, Mango and Orange. The mycelium is entirely superficial and does not penetrate the leaves, the fungi living on the sweet juices excreted by aphides, scale and other insects. These fungi, unless exceptionally numerous, do very little harm to the trees. Preventive measures should aim at destroying the insects.

*Rosellinia bunodes* is a species which has been found to be very destructive to forest trees, such as *Litsaea angustifolia*, *Schleichera trijuga* and others, in Mysore and Assam.

The roots are first attacked and the fungus is best recognised by the clusters of small, round, black *perithecia*, containing the asci, which appear at the base of the attacked stems just above the ground surface. These perithecia have a carbonaceous structure and appearance and can be crushed in the fingers like fragments of coal.

119. *Basidiomycetes.*—This group includes the most highly developed forms of fungi among which are those commonly known as Mushrooms and Toadstools. The hyphæ are septate. There is no sexual reproduction. The asexual spores are developed on elongated, club-shaped, terminal cells of the hyphæ, which are called *basidia.* These basidia are usually placed close together, side by side, and form the *hymenium* or *hymenial layer.* At the top of each basidium are situated four spores, each on a little stalk. This hymenial layer may be smooth and flat, it may cover the sides of thin lamellæ or gills, it may line the interior of pores or tubes, or it may cover the surface of raised spikes, knobs, or irregular folds. A large number of species are known to be injurious to Indian trees, of which only a few can be mentioned. Basidiomycetes.

*Armillaria mellea* (perhaps better known as *Agaricus melleus*) is a very destructive species in Europe and is believed to occur in India.

In Europe it is particularly destructive to coniferous trees. It is one of the few species characterised by the development of rhizomorphs from which in this case the mushroom-like spore-bearing organs, or sporophores, arise. The sporophore consists of two principal parts, the stalk, or *stipe*, and the umbrella-shaped cap, or *pileus.* On the under-surface of the

pileus are a number of radiating lamellæ, or gills, the sides of which are covered with the hymenial layer, on which the spores are produced. The sporophores are usually found in clumps near the base of the attacked tree—the pileus is yellowish, or brownish, in colour, with dark scales, and the stipe bears a membranous, collarlike ring. The sporophores are edible. The mycelium forms firm white sheets between the bark and the wood on the roots, or at the base of the trunk. The fungus spreads by means of its spores, which are disseminated in myriads as a fine white powder and which are capable of producing a new mycelium, and also by means of the rhizomorphs, which spread through the soil, bore into sound roots and produce a vigorously growing mycelium in them.

*Fomes annosus* causes the well-known Deodar root-disease.

*Trametes Pini* has been found destroying *Pinus excelsa.*

The life histories of these two species is given in detail in *Part V* below.

Much of the so-called "dry rot" of timber which has been used in construction is, in Europe, caused by a fungus named *Merulius lacrymans*, which is believed to occur also in India.

*Fomes Pappianus* is destructive to babul (*Acacia arabica*).

Ustilaginaceæ.

120. *Ustilaginaceae.*—Hyphæ are septate. No sexual reproduction. The mycelium produces dark-brown, or black, resting spores. Each of these on germination produces a short tube from which numerous small conidia called *sporidia* are abstricted. If supplied with sufficient nourishment, as would be the case in a field which has been manured, these conidia are capable of very rapid multiplication, by budding, or sprouting, after the manner of yeast cells. As the nourishment becomes exhausted, each conidium develops a hypha, and proceeds to form the mycelium which produces the resting-spores. These fungi are particularly destructive to cereal crops, such as wheat, oats, maize, and others, and are also found on many wild grasses, the mycelium living in the tissues of these plants and ultimately developing masses of dark-coloured resting spores. These characteristic spores, resembling as they do a sooty powder, have caused the fungi in this group to be characterised by the popular name of *smuts*. Several fungi in this group, *e.g.* one of the commonest species occurring on oats, are characterised by the fact that the mycelium is only able to enter, and infect, the plants attacked when the tissues of the latter are very young and tender, *i.e.* shortly after the germination of the seed. Having once gained an entrance, the mycelium of the fungus spreads through the

tissues of the plant attacked, and as the latter grows, the mycelium grows along with it, without, however, so far as one can see, injuring the plant in any way. The presence of the fungus is indeed only made manifest to the ordinary observer shortly before the time of harvest. The hyphæ of the fungus entering the flowers feed on and destroy the substances which should have been devoted to the development of the grain, and eventually, instead of the ripe corn, we find the soot-like masses of resting spores.

*Ustilago Maydis* is common on maize in India and is easily recognised by the boil-like swellings, or blisters, which may occur on leaves, stem, flowers, or fruit heads. These blisters, which may attain the size of one's fist, contain the spores and, when the latter are ripe, the blisters burst and the dark-coloured spores escape. The maize heads are usually attacked and the grain is consequently destroyed.

Uredinaceæ.

121. *Uredinaceae.* Hyphæ are septate. Sexual reproduction doubtful. The fungi included in this group are characterised by their polymorphism. Several kinds of spores are usually produced by them and their complicated life-history will be best understood from the detailed account of *Puccinia graminis* given below in *Part V*.

Owing to the frequent development of masses of orange-yellow, or rust-coloured, spores, which give the appearance of rusty streaks, or patches, on the leaves of the plants attacked by them, these fungi, in contradistinction to those of the previous group, are popularly known as *rusts*. A very large number of these fungi occur on the leaves of our Indian forest trees and shrubs, but, as a rule, they are not very injurious and are, consequently, not of great importance. Only a few of those which are most noticeable in the forest of the North-West Himalaya will be mentioned here.

One of the most remarkable is that known as *Barclayella deformans* (formerly named *Aecidium Thomsoni*) which causes the orange-red tassels so frequently seen in the forests of Jaunsar-Bawar on the spruce, *Picea Morinda* (see *Plate XV, Fig. 1 (a) and (b)* ). Only the current year's shoots are attacked, these being "stunted, thickened and densely covered with curved needles." Every needle on the attacked shoot is affected and they afford a striking contrast to the straight, healthy needles. The masses of orange-red spores (teleuto-spores) form "two continuous flattened beds on the upper surface" and two smaller beds on the under-surface of the needles. When young, the tassels emit a disagreeable odour. The

attacked shoots eventually shrivel up and turn black. As a rule, the damage done is not great, the leading shoot not being often attacked. The teleuto-spores may, also, be sometimes found on the cone scales (see *Fig. 1 (b)*).

The needles of *Pinus longifolia*, the chir, are often seen to produce prominent, flattened, reddish-yellow blisters, usually about one-fifth of an inch long and one-tenth of an inch high.

These contain the spores (æcidiospores) of the fungus *Peridermium complanatum.* The mycelium lives in the needles, but not much harm results. Sometimes the orange blisters may be seen on the stem, or young branches, and as, in such cases, the mycelium destroys the cambium and young cortex the damage is more severe. This form on the stem is considered to be a variety of the above fungus and is distinguished by the name of *corticola.*

*Peridermium brevius* (see *Plate XV, Fig. 2*) is a fungus closely resembling the last which attacks the needles of *Pinus excelsa.* The blisters are smaller than those caused by *P. complanatum.* *Chrysomyxa Himalense* causes the very noticeable, orange-red blisters often seen on the petioles of *Rhododendron arboreum* and *R. campanulatum.*

*Gymnosporangium Cunninghamianum* (see *Plate XV, Figs. 3 and 4*) is an interesting example, inasmuch as it is one of the many species known in this group, which, for its full development and completion of its life-history, requires to live on two distinct species of plants. Part of its life is spent on the cypress, *Cupressus torulosa*, and the remainder on the pear, *Pyrus Pashia.* On the small branches and twigs of the cypress hemisperical, or elongated, dark brown spore masses (teleuto-spores) arise, which, during moist weather, swell up enormously into gelatinous masses. These soon become yellowish in colour owing to the germination of the teleuto-spores and the formation of small, orange-red conidia, called sporidia, which are abstricted from the teleuto-spore germ-tube as described in the case of the resting spores of the *Ustilaginaceae.* These conidia are capable of developing a mycelium in the leaves of the pear. These leaves ultimately produce conspicuous, thickened patches which may be $\frac{1}{2}''$ in diameter, orange-red above and yellowish below. On the lower surface of these patches, little tubular structures are found, 1—2-mm. long, which are called the *aecidia* and in which the æcidiospores are produced. These spores on germination infect the cypress. This fungus does a lot of harm to young cypress seedlings and plants in Jaunsar. It is thought that the eradication of the

pear near the cypress plantations would lead to the disappearance of the pest, the fungus being then unable to complete its normal life-cycle.

Perhaps the most remarkable rust of all is that called *Gambleola cornuta* which is often seen on *Berberis nepalensis* in Jaunsar and near Mussoorie. It produces clusters of long, black, wavy hairs on the under-surface of the leaves and sometimes on the twigs. Each hair consists of chains of teleutospores which adhere closely to one another (see *Plate XV*, *Fig. 5*).

**Lichens.** 122. Before leaving the great group of the *Thallophytes*, we must shortly consider the curious plants called *Lichens*. The general appearance of a lichen is well known, *viz.* that of a crust on stones, earth, trees, etc., of an irregularly shaped, foliaceous structure adhering loosely to the substratum ; or again, that of a tufted, shrubby mass of elongated branching processes, such as is often seen festooning the stems and branches of trees in cold damp forests of the Himalayas ; while others form gelatinous, jelly-like masses. A lichen consists of two distinct plants which live together, in partnership so to speak, one of these partners being a fungus, usually belonging to the *Ascomycetes*, and the other a minute alga. The green, chlorophyll-containing cells of the latter are enmeshed in the closely woven hyphæ of the fungus, the latter being responsible for the general form and outline of the lichen. The lichen is attached to the sub-stratum by root-like hairs, or attachment organs, developed by the hyphæ of the fungus. The fructification of the lichen is developed by the fungus, but the germinating fungus spores usually perish if unable to find a suitable alga with which to enter into partnership. Lichens are commonly reproduced by minute buds, each of which contains a few algal cells entwined with hyphæ. These are distributed by the wind and grow into new lichens. The gelatinous lichens are usually dark-brown, or olive-green, in colour, while others are usually greyish-green, or yellowish.

**Bryophytes.** 123. We now pass on to the second great sub-division of cryptogams, *viz.* the BRYOPHYTA. The plants in this sub-division are divided into two groups :—

(1) The Liverworts (*Hepaticae*).
(2) The Mosses (*Musci*).

**Liverworts.** Liverworts are minute plants of no forest importance which may be found growing in damp soil, on rocks, tree-trunks and even in the water. Many of them show no differentiation into stem and leaves and possess a lobed thallus, thus resem-

bling the Algæ. They are included in the Bryophyta mainly on account of their life-history and the structure of their reproductive organs. Those which possess leaves usually have the leaves inserted in two rows.

**Mosses.** The mosses are small herbaceous plants, showing a distinct differentiation into a slender, often wiry, stem and small green leaves, which are commonly found growing in damp shady places, on the ground, on trees, rocks, etc.

The leaves are usually arranged spirally and not in two rows as in the Liverworts. They possess no true vascular bundles, and consequently the leaves, which have a very simple structure and are usually only one cell thick, exhibit no distinct venation, although a rudimentary midrib may be present. The roots of these plants do not possess the elaborate structure of true roots, but are very simple organs, consisting of single rows of cells and are known as *rhizoids*. The characteristic fruit of a moss is a stalked capsule, called the *sporogonium*, which contains microscopic spores. These, on germination, develop a growth of minute green filaments called the *protonema*, on which buds arise. From these buds are produced what we know as the moss plant. The microscopic reproductive organs arise in groups at the apex of the shoot, or in the leaf axils. The male organs, termed *antheridia*, are stalked and club-shaped and contain a number of small cells. When mature the antheridium ruptures at the apex and expels these cells. Each of the latter then liberates a minute twisted filament called the *spermatozoid* which is provided with two long cilia. The female organs, termed the *archegonia*, are flask-shaped with a slender neck. The dilated basal portion contains a naked mass of protoplasm called the egg-cell, or *oosphere*, which lies in the bottom of the archegonium like jelly in a flask. The spermatozoids, swimming by means of their cilia, in the dew or rain water with which the sponge-like moss tufts are so often saturated, reach the archegonium, pass down its neck and one of them penetrates the oosphere. With the fusion of the protoplasm of these two bodies fertilisation is accomplished and the fertilised oosphere, which is now called the *oospore*, surrounds itself with a cell-wall and at once begins to grow and to divide. After the first cell-division has taken place, the body is no longer called the oospore but the *embryo*. By further growth and division this embryo eventually develops into the sporogonium, bearing the well-known moss-capsule at its apex and with its foot sunk in the tissues of the moss plant. The capsule itself is called the *theca* and it is often provided with a long stalk called

the *seta.* In this capsule are produced the asexual spores. As the embryo develops in the archegonium, the wall of the latter is stretched and eventually ruptures, a portion of the torn investment being carried up on the capsule, as the seta elongates, and thus forms the cap, or *calyptra.* The capsule is usually closed, until ripe, by a lid called the *operculum* and a row of minute teeth, called the *peristome,* is often found fringing the upper edge of the capsule inside, just below the operculum. We thus see that there are two distinct stages in the life-history of a moss, the general form and appearance of the plant varying considerably in the two stages. There is thus the sexual stage, the ordinary moss-plant, which arises from the asexual spore and produces the sexual reproductive organs. As a result of the sexual process of fertilisation, the oospore is formed, and with this commences the asexual stage which ends with the production of asexual spores. Each of these stages is called a generation, and when they alternate regularly, as in the moss, the phenomenon is termed an *alternation of generations.* The sexual generation is called the *Oophyte,* or Egg-plant, and the asexual the *Sporophyte,* or spore-plant. The former arises from a spore produced asexually, the latter from a spore produced sexually. The life-history of the moss may be shortly expressed as follows :—

*Sporophyte* — *Oophyte*

Spore ——————→ Protonema
Moss Plant
♂ antheridia — ♀ archegonia
spermatozoid = oosphere
Sporogonium ←—————— oospore

124. We now come to the third and last great group of cryptogams, *viz.* the PTERIDOPHYTA. **Pteridophytes.** The plants in this group exhibit a distinct differentiation into root, stem and leaves and possess true vascular bundles, while in the case of these plants, as in the *Bryophyta,* **Ferns.** there is a distinct alternation of generations. The plants of most forest importance included in this group are those known as the Ferns (*Filices*). The leaves of ferns are called *fronds,* their venation is usually *furcate* and their vernation *circinnate.* The young stem and leaf-stalks are usually

provided with remarkable, brown, scaly hairs called *ramenta*. The primary root does not persist and form a tap root, but soon dies back, its place being taken by adventitious roots springing from the stem or leaf-stalks. Most ferns are herbaceous with a creeping rhizome of which the common bracken (*Pteris aquilina*) is a good example and which sends up each year one or more large fronds. Others, however, are known as Tree Ferns and attain a height of some 50 feet and a diameter of 1 foot with fronds 12 feet in length. In their general appearance these Tree Ferns resemble some species of Palms with their unbranched stems and terminal rosettes of large pinnate leaves. The venation and vernation of the leaves, however, is usually very characteristic, while the stem exhibits a different structure from those of other woody plants. The stems of the Pteridophytes contain no permanent cambium and hence there is no secondary growth in thickness. The closed vascular bundles are usually concentric and arranged more or less in a circle. A section across the stem of a Tree Fern therefore shows :—

(1) A central portion of cellular tissue which often decays and leaves a hollow in old stems.
(2) An outer mass composed of the bases of the fallen leaves and adventitious roots.
(3) An intermediate zone between (1) and (2) containing the closed vascular bundles, each of which is usually crescent-shaped with a dark-coloured border.

On the fern fronds and usually on their under-surface are produced the little capsule-like spore-cases, or *sporangia* which to the unaided eye look like little granules. Those leaves which bear the sporangia are distinguished from the barren fronds by the term *sporophylls* (=spore-bearing leaves). The sporangia are usually collected in groups, each group being termed a *sorus*, and in many cases they are protected when young by an outgrowth of the leaf-tissue called the *indusium*. The rupturing of the sporangium results in the dispersal of the microscopic spores, each of which, on germination, is capable of producing a small, flat, usually heart-shaped structure called the *prothallium*, which resembles a minute cordate leaf and is usually considerably less than an inch in diameter. This usually contains chlorophyll, and, developing numerous root-hairs from its under-surface, becomes free from the spore. On the under-surface of the prothallium arise the microscopic reproductive organs, termed antheridia

and archegonia, which are, in the main, similar to those described above for the mosses, only of somewhat simpler structure. The oosphere contained in the archegonium, on being fertilised by one of the spermatozoids liberated by the antheridia, becomes an oospore, surrounds itself with a cell wall and proceeds at once by growth and cell-division to develop into the young fern plant. The latter remains attached to the prothallium by a special organ termed the *foot*, by means of which it obtains its nourishment from the prothallium until, with the development of its own leaves and roots, it becomes independent and then the prothallium withers and dies. The oophyte in the fern, therefore, is represented by the prothallium, while the fern plant itself is the sporophyte. The prothallium of the Pteridophyta is consequently homologous with the protonema and what we call the "plant" of the Bryophyta, while the "plant" of the Pteridophyta is homologous with the sporogonium of the Bryophyta. The life history of the fern may be shortly expressed as follows :—

```
 Sporophyte                                   Oophyte
 Spore ————————————————————————————————————— Prothallium
   ↑                                              |
   |                                  ┌───────────┴───────────┐
   |                            ♂ antheridia            ♀ archegonia
   |                                  |                       |
   |                            spermatozoid       =      oosphere
   |                                              |
 Fern Plant ←——————————————————————————————— oospore
```

It should be noted that in both the Bryophyta and Pteridophyta water is necessary for fertilisation, to enable the spermatozoids, which swim in the water, to reach the archegonia.

The Pteridophyta are usually sub-divided into the following three groups :—

*Classification of Pteridophytes.*

*Ferns, Horsetails, Club-mosses.*

1. *Ferns* proper. Plants with well-developed large leaves. Sporophylls are usually similar to the foliage leaves and are not aggregated into cone-like structures. Each sporophyll usually bears numerous sporangia.
2. *Horsetails.* Plants with well-developed stems with distinct nodes and internodes, more or less ribbed and with small leaves in whorls, forming a sheath at each node. The small peltate sporophylls are aggregated into a cone-like flower at the apex of each fertile shoot.

3. *Club-mosses.* Plants with numerous small scattered leaves. Sporophylls resemble foliage leaves but are sometimes aggregated into conelike flowers. Sporangia are borne singly either on the upper surface of the sporophyll, or on the stem.

Now, in the true ferns, the asexual spores are all alike and one and the same prothallium bears both antheridia and archegonia. In some Pteridophytes, however, the spores are of two kinds, the larger ones being termed *macrospores* and the smaller ones *microspores.* These are contained in separate sporangia which are called, respectively, *macrosporangia* and *microsporangia ;* the leaves bearing the former being the female sporophylls and the leaves bearing the latter the male sporophylls. From the macrospore is developed a female prothallium which produces only archegonia and from the microspore a male prothallium producing only antheridia. Moreover, in such plants, the prothallium is in every case pulled further back into the spore, from which it now never becomes independent, as we have seen to be the case in the ferns. The male prothallium in particular becomes very much reduced and consists of only a few cells. Moreover, in the Horsetails and some Club mosses the sporophylls are aggregated into small, cone-like flowers. These plants thus lead us up to the great group of the most highly developed plants, known as the :—

Phanerogams.

125. *Phanerogams.*—This contains all the plants which are not included in the groups already enumerated and briefly described above, and hence it includes practically all our forest trees and shrubs. These plants exhibit a distinct differentiation into true root, stem and leaves, and possess true vascular bundles. They are characterised by the production of true *seeds*, and the majority possess flowers containing structures which we at once recognise as stamens and carpels. In Phanerogams, as in the higher Cryptogams, there is an alternation of generations, although at first sight this is not obvious, owing to the great reduction in the oophyte, that which we see and recognise as the "plant" being the sporophyte. The various organs and members of phanerogamic plants were described and received definite names when the life histories of most of the cryptogams were very imperfectly known. This led to different names being given to organs which are really homologous and this has resulted in further obscuring the resemblances between the plants of these two

great groups. Thus we find that the male and female sporophylls of phanerogams are called *stamens* and *carpels* respectively. The sporophylls with the portion of the shoot on which they are borne constitute the *flower*, while in many cases other leaves surround the sporophylls and form a *perianth.* The microsporangia are the *pollen-sacs*, the macrosporangia, the *ovules.* The microspores are the *pollen grains*, the macrospore is the *embryo-sac* ; both kinds of spores containing as usual a single nucleus, the division of this nucleus in each case is the first step towards the formation of a prothallium (*i.e.* the oophyte). The male prothallium is always minute and consists of only a few cells, the most noticeable portion of it being the so-called *pollen-tube.* Spermatozoids are rarely formed and are usually represented by two small, naked, nucleated, male cells which travel down the pollen tube and eventually pass out at the apex. The cells arising from the repeated nuclear division in the macrospore constitute the female prothallium, which is sometimes large and forms the tissue known as *endosperm.* In the prothallium an oosphere arises, either as a naked cell, or in an archegonium. Fertilisation is accomplished with the fusion of the nucleus of a small male cell with that of the oosphere ; while, from the resulting oospore, the embryo, or young sporophyte, is produced. Here then the prothallium never has an independent existence apart from the spore which has produced it. The female prothallium remains altogether inside the macrospore, the latter remains inside the macrosporangium, and the latter remains for a long time attached to the parent plant or sporophyte. Eventually the whole macrosporangium with the macrospore and contained embryo separates from the parent plant as the *seed.* Thus the oophyte does not form a distinct and separate stage in the life history. The embryo during its growth and development frequently absorbs the rest of the tissue formed in the macrosporangium and consequently the kernel of the ripe seed consists of the embryo alone. In such cases the seed is said to be *exalbuminous.* In other cases some of the tissue of the macrosporangium persists in the ripe seed and the latter is said to be *albuminous.* Such persistent tissue is distinguished as *endosperm*, or *perisperm*, according as it has developed within, or without, the macrospore. See also p. 58. Phanerogams are divided into the two following main divisions :—

I. Gymnosperms.
II. Angiosperms.

Gymnosperms.

126. *Gymnosperms.* The ovules are naked and not enclosed in an ovary. The pollen grains are thus able to come directly in contact with the micropyle of the ovule. The oophyte developed by the macrospore is represented by a mass of tissue which completely fills the macrospore (embryo sac) and is called endosperm. The oosphere is contained in an archegonium. There is no distinct perianth to the flower. The flowers are unisexual. Cotyledons, two or more, usually appearing above ground on germination, are perennial trees and shrubs, usually resinous. Leaves are often acicular. The primary root persists and forms a tap-root. The vascular bundles are open, collateral and arranged in a circle round the pith. Secondary growth in thickness takes place by means of a normal cambium ring and the stem consequently exhibits a central pith, with distinct bark and wood, while it increases in size by rings of new growth added at the outside of the wood-cylinder and immediately beneath the bark. True vessels are not present in the wood except in that of *Gnetaceae.* Gymnosperms are sub-divided into the following three orders:—

Cycadaceæ.
Coniferæ.
Gnetaceæ.

Cycadaceæ.

127. *Cycadaceae.* In this order are included the plants which are often seen in Indian gardens and are sometimes wrongly called the Sago Palms. The columnar, usually unbranched, stem with the terminal rosette of large pinnate leaves of these plants gives them a superficial resemblance to the Palms. In India they rarely attain a greater height than 30 feet. The wood is characteristic owing to its possessing alternate layers of woody and bast tissue with no true vessels, and the pith is usually large. The flowers have no perianth and are diœcious. They are situated at, or near, the apex of the stem, the male flower being a cone with a number of thick scales, on the under-surface of each of which are situated numerous pollen-sacs. In the female Cycas tree the characteristic macrosporophylls, or carpels, arise on the apex of the main stem, taking the place as it were of the foliage leaves. Although smaller and not green, these carpels somewhat resemble the foliage leaves. The upper portion of the carpel is pinnate, the ovules, which may attain the size of small plums, being borne laterally on the basal portion in the position of leaflets. *Cycas Rumphii*, and *C. pectinata* are well-

known Indian trees, from the stems of which sago or starch is obtained.

128. *Coniferae.* These include much branched woody plants with undivided, usually acicular, leaves. The wood does not contain true vessels but often possesses resin ducts. The flowers have no perianth and are usually cones, *i.e.* shoots carrying scale-like sporophylls, the latter bearing the ovules and pollen-sacs. In this group are included very many important forest-trees such as the Pines, Firs, Spruces, Cedars, Larches, Cypresses, Junipers and others. **Coniferæ.**

129. *Gnetaceae.* The leaves are undivided, often broad and usually opposite. The stem and branches are jointed at the nodes. The flowers are not cones, they have a rudimentary perianth and are usually arranged in slender spikes. The wood contains true vessels. **Gnetaceæ.**

*Ephedra Gerardiana* is a small, apparently leafless, shrub, fairly common in Jaunsar.

Several species of *Gnetum* occur in India. They are generally climbers with broad, well developed, opposite leaves.

130. *Angiosperms.* The macrosporophylls, or carpels, form closed cavities called *ovaries*, within which are contained the ovules. The pollen is received not on the micropyle of the ovule, but on a specialised portion of the carpel called the *stigma*. The oophyte developed by the macrospore is small and consists of only a few cells which are usually without cell-walls, one of these naked cells being the oosphere. After fertilisation has taken place, however, the cavity of the spore becomes filled with tissue which has also been called endosperm, but which is clearly not the same, morphologically, as the endosperm of Gymnosperms which is developed before fertilisation. The flowers are, typically, hermaphrodite with a perianth. The Angiosperms are sub-divided into two groups :— **Angiosperms.**

Monocotyledons.

Dicotyledons.

131. *Monocotyledons.* The embryo has typically one cotyledon which usually remains below the ground. These plants are usually herbaceous and are rarely shrubs (species of *Smilax* for example), or trees (*Palms* and *Bamboos*). The flowers have their parts typically in whorls of three. The leaves usually have parallel venation. Species of *Smilax* and *Dioscorea* are the most important exceptions with reticulate venation. The leaves **Monocotyledons.**

are usually without stipules, with a well-developed leaf base and not disarticulating readily from the parent axis. The primary root soon dies and its place is taken by adventitious roots which arise successively higher and higher on the stem. The collateral, closed vascular bundles are scattered irregularly through the stem. Secondary growth in thickness rarely occurs, but when it does and a cambium ring is present, the latter does not form a continuous ring of wood on the inside, but produces closed vascular bundles scattered in fundamental tissue. Perennial stems usually have no distinct bark, no annual rings, and no medullary rays, but possess true vessels.

Dicotyledons.

132. *Dicotyledons.* Embryo has typically two opposite cotyledons which may remain within the seed, or become green and appear above the ground in germination. These plants are herbs, shrubs or trees. The flowers have their parts usually in whorls of 5 or 4. The leaves generally have reticulate venation. The leaves often have stipules, rarely have a conspicuous sheathing leaf-base, and usually disarticulate freely from the parent axis. The primary root usually persists to form a tap root. The collateral, open vascular bundles are arranged in a circle. Secondary growth in thickness takes place in perennial stems by means of a complete cambium ring which continually forms woody tissue on the inside and cortical tissue outside. Perennial stems usually possess distinct bark, annual rings, medullary rays and numerous vessels.

Synopsis of the Sub-divisions of the Vegetable Kingdom.

133. The following Key will now help us to bring into focus the principal groups of the Vegetable Kingdom which we have considered above :—

CRYPTOGAMS. Plants not forming true seeds.

| | | |
|---|---|---|
| THALLOPHYTA. Cellular plants with no differentiation into stem and leaves. An alternation of generations is altogether wanting or irregular. | *Algae* . . | Plants containing chlorophyll, chiefly aquatic. |
| | *Bacteria.* — Very minute plants multiplying by splitting. *Fungi.* | Colourless plants without chlorophyll. |

| | | |
|---|---|---|
| BRYOPHYTA.<br>Cellular plants usually showing a differentiation into stem and leaves, and with a distinct alternation of generations, the oophyte constituting "the plant." | *Mosses* . .<br>*Liverworts.*—Minute plants often with no differentiation into stem and leaves | Plants containing chlorophyll. Chiefly terrestrial. |
| PTERIDOPHYTA.<br>Plants showing a differentiation into stem and leaves. Possess true vascular bundles, and with a distinct alternation of generations, the sporophyte constituting the "plant." Chiefly herbaceous. Only a few of the Ferns attain the dimensions of trees. | *Ferns.*—Plants with relatively large leaves. Sporophylls are not aggregated into cones.<br>*Horsetails.*—Plants with distinct nodes and internodes and small leaves in whorls. Peltate sporophylls aggregated into cone-like flowers.<br>*Club-mosses.*—Plants with small scattered leaves. Sporophylls resemble foliage leaves, but are sometimes aggregated into cone-like flowers. | |

PHANEROGAMS. Plants forming true seeds.

| | |
|---|---|
| GYMNOSPERMS.<br>Ovules not enclosed in an ovary. Trees and shrubs. | *Cycadaceae.*—"Sago Palms" or Cycads. Flowers have no perianth and are usually cones.<br>*Coniferae.*—Freely branching trees and shrubs. Flowers cones with no perianth.<br>*Gnetaceae.*—Flowers are not cones and have a rudimentary perianth. |
| ANGIOSPERMS.<br>Ovules enclosed in an ovary. Trees, shrubs and herbs. | *Monocotyledons.*—Embryo with one cotyledon.<br>*Dicotyledons.*—Embryo with two opposite cotyledons. |

## Chapter III.—THE ORIGIN OF SPECIES.

Struggle for existence.

134. On all sides around us, in nature, the great battle of life is always going on, or, as it is often termed, the *struggle for existence.* On all sides we find organisms directly destroying others, carnivorous animals preying on other animals, some plants, such as fungi, killing and feeding on other plants, while everywhere animals are found injuring and destroying plants. Not so obvious, but no less severe, is the competition between similar organisms for the same kind of food. This is usually most severe between organisms which require the same food materials and similar external conditions for their existence. To realise this we have only to watch the development of crowded seedlings in a nursery seed-bed, or in the forest. The roots of all are ramifying in the same layers of soil and are competing with each other for the same moisture and the same solutions of mineral salts—the stems of all are competing in their endeavours to expand their green leaves in the same light and air. Some individuals are soon seen to be growing more slowly than their vigorous neighbours—their leaves turn pale, their stems grow weak and finally they die, while the seedlings around soon cover over the gaps caused by their disappearance, leaving no trace of those which have been starved and killed. The Forester, therefore, in order to secure the best development of the individuals belonging to his valuable species, is obliged to interfere in this struggle between plant and plant and to transplant his seedlings and to clean and thin his young woods. Realising, also, that the competition between plants belonging to different species is often scarcely less severe, he takes measures to prevent undesirable species interfering with the healthy development of his valuable trees, while the agriculturist carries out essentially similar operations in his fields, by eradicating the "weeds" which, year after year, appear, in addition to those plants which alone he wishes to cultivate. In order to maintain itself, also, every organism is obliged not only to fight against other living organisms, but, in addition, to struggle against the unfavourable factors of its non-living environment, *e.g.* climatic influences, great heat and cold, drought, excessive moisture, and so on. The importance and universality of this natural phenomenon of the struggle for existence is perhaps best realised by a

consideration of the great powers of increase possessed by all living organisms. It has been calculated, in the case of a small herbaceous plant, about two feet in height, which produces on an average 10,000 seeds annually, that, if all the seeds developed and produced fertile plants, each of which in their turn ripened a similar number of seeds and so on, all the dry land on the earth would be completely occupied by such plants at the end of five years. Many plants, also. produce a greater number of seeds than the example given, and an ordinary Tobacco plant is calculated to produce, on an average, 360,000 seeds annually. That no single species is able to actually monopolise the earth in this way is due to the struggle for existence.

"While the offspring always exceed the parents in number, generally to an enormous extent, yet the total number of living organisms in the world does not, and cannot, increase year by year. Consequently every year, on the average, as many die as are born, plants as well as animals; and the majority die premature deaths. * * There is thus a perpetual struggle among them which shall live and which shall die; and this struggle is tremendously severe, because so few can possibly remain alive."*

**Importance of Sub-species and Races.**

135. It has been noted above that in many Floras all sub-divisions of the species are indiscriminately termed varieties. Obviously such varieties are by no means all of the same value. We may find that the distinguishing characters of a particular variety are always, under varying conditions of existence, transmitted unchanged from the parent to its immediate offspring, that the variety is, in fact, a true sub-species. Since the characters which distinguish a particular sub-species from the rest of its species may include the power of producing a valuable commercial product, immunity from particular forms of injury and disease caused by fungi, insects or other injurious factors such as frost, and so on, a knowledge of such sub-species is obviously of great importance for the Forester, as well as for the Gardener and Farmer. Many races, again, the distinguishing characters of which only remain constant under certain conditions of existence and which are therefore of subordinate importance in nature, are of considerable importance in cultivation where the conditions of their existence can be regulated so as to keep their characters constant. The selection of the most suitable sub-species and races for culti-

* *Darwinism*—by A. R. Wallace, page 11.

vation, therefore, plays a very important part in modern agriculture and horticulture. In a single field of wheat, or other cereal, several different sub-species may, and usually do, co-exist. The most desirable of these may be observed to constitute a very small proportion of the crop when cultivated without special care. The reason for this is usually to be sought in the struggle for existence, the conditions being more favourable to the less valuable sub-species and thus enabling them to overcome and kill out their less vigorous neighbours, just as we have seen to be the case in a crowded seed-bed, and this is especially the case in unfavourable seasons. The Farmer, therefore, carefully isolates and saves the seeds of the desirable sub-species, say those with the largest ears and the biggest, most numerous grains, and cultivates it separately, treating all other kinds of the cereal as weeds, and endeavouring, as far as possible, to eliminate them from his fields.

Again the distinguishing characters of some races of plants do not remain constant when they are grown in the vicinity of other plants by which they are easily fertilised. This does not prevent such plants being of great value to the horticulturist who endeavours to isolate such races and to prevent, as far as possible, intercrossing with allied plants. The beds in which such plants are grown, however, can rarely be separated sufficiently to prevent occasional crossing by bees, which carry the pollen from one to the other.

Frequently, therefore, the seed of some of our best garden flowers, as sold in the market, cannot be guaranteed as pure, some of the resulting seedlings invariably showing aberrant characters, owing to their parents having been crossed by allied forms.

**Hybrids.** **136.** Plants raised from the seed produced by the crossing of two plants belonging to distinct species, or varieties, are called *hybrids*, or *bastards*, and are usually distinguished as *species-hybrids* and *variety-hybrids*. Very commonly the crossing of individuals belonging to distinct species is accompanied by entire or partial sterility, *i.e.* there is less chance of fertile seed resulting from the cross and of fertile individuals being developed from such good seed as may have been produced, than is the case in normal fertilisation. Such sterility varies greatly in degree, for while crosses between very nearly related species, or between varieties of the same species, may be, and usually are, perfectly fertile, crosses between species

which are not closely allied are characterised by a considerable degree of sterility and are often entirely sterile. As fertilisation consists essentially in the union of two sexual cells, a portion of the protoplasm of each cell entering into the constitution of the embryo which results from such a union, we should naturally expect the distinguishing characteristics of each parent to become more or less apparent in the hybrid. This is the case and the hybrid is found either to be intermediate between the parents, the characters of both parents being combined in it, or else to resemble one parent more than the other. Occasionally also it may present entirely new characters. In some cases the result of hybridisation is different according to which parent is chosen as the father or mother respectively. Thus a cross may only be possible when an individual of a certain species is always chosen as the father, the reciprocal cross with the same individual as the mother being sterile.

Again, the hybrid in some cases is always found to resemble one parent, *e.g.* the father, more than the other. Fertile hybrids are those which, when fertilised by their own pollen or by that of another individual of the same hybrid cross, produce fertile seed from which fertile plants are developed. Fertile hybrids may be constant, as regards their distinguishing characters, from the first, but in the majority of cases they are found to split, *i.e.* to revert to the parent forms in subsequent generations. In such cases of reversion, however, a few individuals are often found which remain constant hybrids, with characters distinguishing them from both parents. A hybrid may be successfully crossed not only with another hybrid but with one of its parents; if this is repeated, the derivative hybrid obtained from such a cross being again crossed with the same parent and so on, the offspring are found to resemble that parent more and more, and finally to completely revert to it. The hybrid, instead of being crossed with one of its parents, may be crossed with an individual belonging to an entirely distinct species and this operation may also be repeated. In this way it has been found possible to obtain a derivative hybrid in which the characters of six, or even more, different species are combined. Hybrids occur in nature but not very frequently; probably this is partly due to the fact that, in the majority of cases, where the flowers of a plant are simultaneously pollinated by different plants, the pollen of an individual belonging to the same species is *prepotent*, *i.e.* it is able to accom-

plish fertilisation quicker than the pollen of plants belonging to different species. The action of such foreign pollen being thus excluded, hybridisation is prevented. In other cases the plants resulting from hybridisation may be unable to establish themselves in nature, owing to the severity of the struggle for existence with other plants. Among the characters which are frequently possessed by hybrids and which serve to distinguish them from their parents are an increased tendency to variation, a more luxuriant and vigorous vegetative growth, and larger, more brilliantly coloured flowers, which also often tend to become double. For this reason alone hybrids are important in horticulture. The great importance of hybridisation, however, depends chiefly on the fact that it affords a means of combining in one plant the valuable attributes of several, and a species yielding a valuable commercial product which is liable to damage by frost, or to a particular form of disease, may thus be rendered hardy by crossing it with an allied, but hardy, species, the hybrid offspring, while yielding the valuable product of one parent, possessing also the hardy attributes of the other. If such a desirable hybrid is obtained it would of course be carefully isolated and cultivated in such a way as to prevent, as far as possible, intercrossing with other plants. At the same time it must be remembered that the practical attainment of such a result is attended with great difficulties, the greatest obstacles to successful work in this direction being the inconstancy of many hybrids and the comparative sterility of others. For successful hybridisation the flowers of the plant chosen as the mother (if hermaphrodite) should be deprived of their stamens before the latter are mature, the flowers then being covered with paper caps to prevent the access of insects and possible fertilisation by the pollen of other plants. With a clean camel-hair brush the pollen is then taken from the plant selected as the father and gently and lightly applied to the stigmas of the protected mother flowers. The caps are then replaced on the latter. If the cross has been successful the flower will quickly wither, and if this does not occur the cross should be repeated.

**Variations. Fluctuating Variability.**

137. If we examine a large number of adult plants all raised from the seed of a single individual, we shall find a few exceptionally tall, and a few exceptionally short, specimens, while the great majority will be seen to be intermediate between these two extremes, of moderate, or medium height, and differing very

slightly from each other in this respect. A large number of adult men placed in a row would give a similar picture of variability. Again if we examine and carefully measure the leaves on a tree, we find a few unusually large, and a few unusually small, specimens, while the great majority are intermediate and of moderate dimensions. The same thing occurs in the shape and size of seeds and fruits. Numbers also vary in the same way, as is seen in the number of lateral veins in leaves and leaflets. Small numbers, however, are usually more constant than large numbers and a considerable degree of constancy usually characterises the numbers of the different floral organs. Such characters as the percentage of sugar in the sugarcane, or of starch in potatoes, as well as the power of resistance to frost, and so on, obey the same rule, and we may say that this phenomenon of *Fluctuating Variability* is almost universal. This type of variation is obviously directly dependent to a great extent on nutrition, and therefore, indirectly, depends on the factors which together constitute the plant's environment. On vigorous, well-nourished coppice shoots the leaves are as a rule considerably larger than on normal branches, while gardeners know that, by diminishing the total number of flowers or fruits on a plant, and by thus increasing the amount of food available for the remainder, the size of the latter can be materially increased. The various factors of the environment also have a marked effect. A plant accustomed to a damp locality, on being transferred to a dry one, may be so changed in appearance as to resemble another species. In such cases the size of the leaves and the growth in length of all shoots are often greatly reduced and thorns and spines are frequently developed. The common Brinjal (*Solanum Melongena*), for instance, when cultivated in a well-watered garden, has large leaves which are often almost unarmed. It may, however, be often seen as an escape from cultivation, in dry rocky places, with small and intensely prickly leaves. In India also we have several examples of plants which, in dry localities, are erect shrubs, or small trees, and in damp situations climbers—such as *Toddalia aculeata* and *Alangium Lamarckii*. The nature of the soil also frequently appears to affect plant characters, and individuals growing in soil containing large quantities of lime, or other substances, may differ very considerably from individuals of the same species growing in ordinary soil. Light is also a factor affecting the form of plants, although it is sometimes difficult to decide how far an observed result is to be ascribed to any one

factor, such as light, and to what extent other factors, such as available moisture, may have contributed to it. In shady situations, in the case of one and the same species, not only may leaves be found to be thinner, and often of a different colour, consistency, size, and shape, than they are in places exposed to bright sunlight, but their anatomical structure may also be fundamentally changed, and we find sun-leaves with an epidermis devoid of chlorophyll, provided with a thick cuticle, and with well-developed palisade tissue, while shade-leaves often have no palisade tissue and an epidermis with very thin walls and provided with chlorophyll. Anatomical variations also may be found in the petioles, stems and roots. Cases are known of so-called *dimorphic* species which are able to maintain themselves on high mountains and also in the lowlands, or on dry land, as well as under the water, and variability is thus seen to be a very useful character, inasmuch as variable plants are thus enabled to adapt themselves to varying conditions of existence and to widely extend their area of distribution. Variations of the kind now under discussion appear to us to be temporary and inconstant, and individuals belonging to the alpine—or aquatic—form of a dimorphic species, after existing for many generations on the mountains or under water, are found to assume the characters of the lowland—or terrestrial—form, respectively, when cultivated in the plains or on dry land. At the same time cases are known in which plants under the influence of certain conditions have undergone a slow but progressive change and have thus acquired definite characteristics which have become constant and hereditary. With regard to this point the study of bacteria is of special value seeing that, in their case, "experiments * * can be readily extended over a far greater number of generations than in the case of flowering plants, for a bacterium which divides once an hour passes through as many generations in ten days as an annual plant does in 240 years."* By continued cultivation under special conditions, it has been found possible to permanently eliminate in certain species of bacteria the power of producing poisons, pigments, and even the important character of the power of spore production. Such changes do not occur suddenly, but only gradually become fixed and hereditary and if, after short exposure to the special conditions, the bacteria are returned to their original environment, the power of pro-

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* *Physiogy of Plants*, by Dr W. Pfeffer, Volume II, pages 192--193.

ducing poison, pigment, or spores, returns. Attention has hitherto been confined to the so-called fluctuating variability, and it must be remembered that, although in a series of such variations, the two extreme forms may be widely dissimilar, these are always linked together by a number of intermediate forms which differ very slightly from each other; there is no gap in the chain and no sudden and considerable variation, only a number of very slight differences. We have also seen that such variations are inconstant, although in some cases at least, *under suitable conditions*, they can be gradually fixed and rendered hereditary.

**Spontaneous Variations, Sports, Mutations.**

In contrast with such variations are those known as *spontaneous variations*, *sports*, or *mutations*. Our knowledge of these and of their mode of occurrence in nature depends chiefly on the experiments carried out by Professor Hugo De Vries. He has demonstrated that plants of the species *Oenothera Lamarckiana* in addition to producing normal offspring bearing the characteristic marks of their parents, produced also considerable numbers of individuals which possessed definite and appreciable characters not seen in their parents. Such individuals are termed *mutants*; they suddenly come into existence, there is no progressive change, and no intermediate forms are found linking them with the species from which they spring, they are due in fact to a sudden variation, *i.e.* a mutation. A mutant, when isolated and fertilised with its own pollen, is found to be constant from the time of its origin and to transmit its essential characters truly to its offspring. This constancy sharply distinguishes mutations from the inconstant fluctuating variations. The species mentioned was found to produce several different types of mutants, differing in various ways from the original form, several individuals of each type usually appeared simultaneously, while each type was liable to be reproduced at intervals by the parent species. The causes of mutations are at present unknown. The great majority of species in nature are fixed and constant, but from the case of this *Oenothera* it appears possible that all species at some period of their existence throw off mutants in considerable numbers. Such a mutating period probably forms only a small part of the total life of a species. Such a period moreover does not necessarily involve the death of the parent species which, as seen in this *Oenothera*, in addition to producing mutants, may continue to transmit its specific characters truly to the majority of its offspring. Mutations are not entirely confined to such mutating periods; occasional mutants may arise at any time,

but so far as is at present known, they are rare. The occurrence of double flowers in species with usually single flowers, of regular flowers in species with usually irregular flowers, of divided leaves in species with entire leaves, of a weeping, or fastigiate, habit in trees and shrubs with an erect, or spreading, crown, respectively, are among the most common examples of mutations at present known.

Monstrosities.

Very striking variations which give the impression of an altogether abnormal structure are called *monstrosities*. They are often termed malformations and frequently give rise to diseased conditions. They are of rare occurrence in nature; the cauliflowers and turnips of cultivation are believed to have arisen from monstrosities. Finally it must be noted that remarkable variations in the form of plants may be caused by insects and fungi, which may, for instance, be responsible for the peculiar structures known as "galls" and "witches' brooms." Mutilation also may exercise a far-reaching effect such as is seen in plants which are continually browsed or grazed by animals, while some annual species may be made perennial by removing the flower buds and thus preventing their reproduction.

Variations due to Insects, Fungi and Mutilation.

Heredity.

138. By *heredity* is understood the transmission of characters from a parent to its offspring. This transmission is rendered possible in plants by means of their powers of sexual and asexual reproduction. Many variations can only be transmitted truly to the offspring by asexua propagation, and for this reason individuals which exhibit a desirable variation are usually propagated in horticulture by asexual methods. This is particularly the case with hybrids which are frequently very inconstant if propagated by seed. The younger a plant or organ is, the greater will be the effect of any factor which is capable of influencing its development, and the early stages of the growth of the embryo constitute the most susceptible period. If this period could be cut out, as it were, from a plant's life history we should expect it to be less subject to variation and to resemble its parent more closely than would be the case if the individual were raised from seed, and this is precisely what is effected by asexual propagation. It must, however, never be forgotten that in sexual reproduction effected by the crossing of two distinct individuals a portion of the protoplasm of each parent enters into the composition of the young plant, which must therefore inherit something from its father and something from

its mother. When both parents possess similar characters the offspring will naturally tend to strongly resemble the mother plant, although this depends to some extent on the conditions under which the young plant develops, but if this is not the case the results of the cross may be very various, as has been noted in the remarks on hybrids. We have also seen that, when a hybrid form is repeatedly crossed with one of its parents, it tends to quickly revert to that parent form, and in this way sexual reproduction may help to eliminate new variations and to keep species constant in nature. A character which may appear to have been lost is frequently found to be really only dormant, or latent, and although it may be inherited in this state during many generations it is always likely to reappear and again become active. This phenomenon of the reappearance in a plant of an ancestral quality which has been latent in its parents is termed *atavism.*

139. We have seen above that a large proportion of all living organisms which come into existence must perish prematurely and that in nature those which are best adapted to the conditions under which they exist are selected, or chosen, as it were, by nature, and survive, while the remainder are rejected and perish. This Survival of the Fittest, therefore, is seen to be the result of the so-called Natural Selection. Selection has been well likened to a sieve, only those individuals which possess the necessary qualifications are able to remain and are selected, while the remainder pass through the sieve and are rejected. It is advisable to distinguish two kinds of selection, *viz.* that which selects a particular sub-species, or race, from among other sub-species and races, and that which selects particular individuals within one and the same sub-species, or race. An example of the first occurs when, in a field of wheat, a single sub-species is selected from among the others growing with it and is then isolated and separately propagated. The same thing occurs in nature when, from a number of mutations, only those which are best adapted to the conditions of life are selected and survive, while the others perish. In addition to this, however, we know that, within one and the same sub-species, or race, there is always fluctuating variability—that no two individuals are ever exactly alike—and that the same quality or character is exhibited in different degrees by different individuals. Hence it might be inferred that breeding entirely from those individuals which exhibit a desirable character in a marked degree would result in the production of similarly characterised

Selection.

offspring ; and that a race could, in this way, be improved and confined, as it were, to a few of the best individuals, the large number of moderate, or inferior, individuals usually occurring in the race being thus excluded. To a great extent this is found to be the case, and modern horticulture and agriculture depend largely on these two principles of (1) the selection of the most suitable race or sub-species and (2) the improvement of the selected strain by breeding only from the best individuals. In cases of fluctuating variability the greater the number of individuals examined the more chance there is of finding an individual which exhibits a particular character in an extreme degree and for this reason large cultures are often resorted to in horticulture. Professor Hugo De Vries records a case in which 40,000 plants were cultivated, only a single individual being finally selected from this multitude for further propagation, all others being destroyed. Such an individual, when found, can only be propagated with certainty by asexual reproduction. Many plants, however, cannot easily be propagated in this way and such large cultures are very inconvenient. In addition to this the asexual method of reproduction affords no means of effecting further considerable improvement of the race. It is, however, found that such desirable variations can also be obtained and to a certain extent be propagated by sexual methods. Experience shows that if individuals exhibiting a certain character in a marked degree are chosen as parents, although the average of the offspring raised from their seed do not exhibit this character in so high a degree as their parents, they do show a distinct improvement in this respect and are superior to the average of the race from which they have arisen. By continuing this method for some generations the same degree of improvement can be obtained with comparatively few individuals, which could only be obtained in one generation by cultivating a very much larger number of plants. Moreover the sexual method possesses the great advantage of enabling us to continue the work of improvement. This principle is a very important one in modern agriculture. The fact that not one, but several, characters have almost invariably to be taken into consideration is one of the great difficulties in the way of successful practical work in this line. If, when selecting certain individuals in a race of wheat, we were only to pay attention to the quantity or quality of grain yielded, we might select those plants which are also very susceptible to disease or climatic influences, and the selection would thus effect no practical improvement. It is generally recognised that the

best results are, as a rule, obtained by selecting not those individuals which exhibit the best visible characters, but those plants which are found to produce the most desirable offspring; in other words, the value of a plant is gauged not by its visible attributes but by its power to transmit desirable qualities to its descendants. For this purpose the seeds of each individual are sown separately and, to obtain an average value for the offspring of each individual, 100 seedlings are carefully examined and their qualifications considered. Only those groups which contain the greatest number of desirable individuals are then selected for further cultivation. This method is based on the idea that a single plant, or even a few individuals, may owe their qualifications not to any inherited attribute but to extraordinarily favourable conditions to which they have been subjected during their own life-time. Although great improvements have been wrought on the lines indicated above, no permanent improvement has, up to date, been effected and no new and constant race has been produced. Experience hitherto gained has shown that whatever standard of selection is adopted, a limit to the improvement effected is soon reached beyond which it is impossible to go, and, further, that when a desirable degree of improvement has been reached, this can only be maintained by continued selection, for if selection ceases, the race soon reverts to its original type.

**Origin of Species in Nature.**

140. Linnæus, the most famous of the early botanists who worked at classification, thought that each species had been separately created at the beginning of the world and that the individuals of a species were only capable of producing other individuals like themselves, *i.e.* that existing species had remained unchanged from the creation. Charles Darwin, however, subsequently proved thatthis was not the case and that, from one species, other and totally distinct species could arise in the progress of time. The theory of evolution in the animal and vegetable kingdoms is now universally accepted as correct, as is also the fact that this evolution is mainly dependent on two factors, which are:—

(1) the variability of living organisms, and

(2) the struggle for existence, owing to which only those organisms are able to survive which are most perfectly adapted to the conditions under which they exist, which are best able to withstand unfavourable conditions of soil, or climate and which can best hold their own against other injurious organisms.

> Such a view also satisfactorily accounts for the fact that everywhere in nature we find animals and plants exhibiting the most beautiful adaptations to the conditions of their environment, by means of which they are favoured in the struggle for existence.

Opinions, however, differ as to which type of variation has played the most important part in the history of species. The variations which are believed to be most important from this point of view may be divided into three main classes as under :—

(1) Variations due to the crossing of different forms, *i.e.* to hybridisation.
(2) Fluctuating variations.
(3) Mutations.

It may also be premised that, in order to form the beginning of a new species, a plant must be able to maintain itself under the conditions of existence to which it is exposed in nature, it must be able to transmit its essential characters truly to its offspring, it must occur in considerable numbers and be sufficiently fertile to produce numerous offspring. Such a plant may possibly result from hybridisation alone. As regards fluctuating variability, experience with bacteria indicates that, if the conditions, to the stimulating action of which the variation must be ascribed, are kept constant, in some cases, at least, a new and constant form may be gradually evolved which may also be able to establish itself as a new species. In the case of plants reproducing sexually, such a progressive change would be aided by natural selection, for all individuals not exhibiting the variation, which, under the circumstances, is favourable to their existence, would perish, while only those possessing the variation in a high degree would remain to cross and produce offspring. We have seen also that new, fertile, and constant, forms in considerable numbers may arise by mutation, and those which are able to survive in the struggle for existence may form the beginning of new species. Just as the small fluctuating variations may be gradually accumulated and increased in the same direction by natural selection, so may be also mutations, for, providing the conditions remain constant, of all the mutants produced during successive mutating periods only those mutants which vary in the same direction will be able to survive, and thus evolution will continue along the same lines, just as with fluctuating

variations, until those marked differences are produced which distinguish the actually existing species in nature. Valuable results, however, in the way of producing new forms have been obtained in horticulture and agriculture by a combination of the operations of selecting the best strains, of crossing distinct strains, and of selecting for propagation those individuals which exhibit the most desirable fluctuating variations, and we must, therefore, be careful not to hastily ascribe to any one type of variation, or to any single factor, pre-eminent importance in the evolution of species in nature.

## Chapter IV.—COLLECTION AND PRESERVATION OF SPECIMENS.

**Collection of Specimens.**

141. It is of the first importance that specimens should be gathered which exhibit those parts and organs, the characters of which are included in the descriptions and keys of our Floras. So far as possible the specimens selected should indicate the average condition and the range of variability of the important organs found on one and the same individual and on the different individuals of the same species found growing together, and in any case should not be confined to those parts, or individuals, which show extreme variations, or abnormal development. The specimens must not be allowed to wither before they are laid in the drying papers and are usually placed, immediately after they are gathered, in a tin case which should be kept as cool as possible. The specimens having been laid in the drying papers are usually placed between two boards with a weight on the top. For camp perhaps the most portable and useful press is one consisting of two pieces of strong wire lattice of convenient size which can be firmly bound together with straps and buckles, or with a piece of thin rope.

The specimens are kept in this until dry, the drying papers being of course changed and dried when necessary, and they can then be packed in boxes in layers between sheets of paper, care being taken to keep them from damp. A small notebook should always be carried in which such details as the vernacular name, dimensions, habitat, habit, and general appearance of the living plant should be invariably noted, on the spot, and not left to memory. To each specimen, before being placed in the drying papers, should be fastened a small label with a number, and great care should be taken to see that these labels do not become subsequently detached. A journal should also be kept up in which the specimens collected should be entered daily, serially, under their respective numbers, with the date. Here also should be recorded the details noted in the field, the name of the plant and natural order (if determined), the results of the inspection of the specimens with diagrams or sketches of the parts examined, the locality where collected, and careful details of all characters observed which are not exhibited by the specimens themselves, such as the colour of the fresh flowers. It is important that all specimens should, so far as possible, preserve their natural appearance and colour, and for

this purpose they must be dried as quickly as possible. The drying papers should be changed at least once a day for the first few days and the following note may well be borne in mind: "Two or three changes of the driers during the first 24 hours will accomplish more than a dozen changes after the lapse of several days. The most perfect preservation of the beautiful colours of some orchids has been effected by heating the driers and changing them every two hours during the first day."* In order to hasten the drying of succulent plants they should be dipped (with the exception of the flowers) in boiling water, and this is also a good plan to adopt in the case of those specimens which are apt to lose their leaves in drying. To reduce the thickness of some specimens, such as hard fruits and so on, they may be thinned by cutting away the underside, care being taken to see that the original shape can be made out.

Preservation of Specimens.

142. The specimens when completely dried should be mounted, and this is perhaps best done by sewing them on to the sheets with a needle and thread, never more than one species being fastened to the same sheet. Fragile specimens must be glued to the sheets, care being taken not to use more glue than necessary, especially on the flowers. Before being placed in the herbarium all specimens should be poisoned to protect them from mould, insects and vermin. Corrosive sublimate (bichloride of mercury) is the poison usually employed which should be dissolved in spirits of wine in the proportion of about ½ oz. of the poison to one pint of spirit. This should be applied to the specimens with a large soft brush. The solution should not be allowed to come in contact with metal or discoloration may result. Leaves and other parts of the specimens which become detached should be placed in small envelopes, the latter then being fastened to the mounted sheets. At the foot of each mounted sheet should be carefully noted the natural order, scientific and vernacular name of the plant, locality where found, date of finding, name of collector and details of useful characters not exhibited by the specimen itself, such as colour of the fresh flowers, habit of the plant, and so on. All the sheets of the species belonging to one and the same genus should be placed in one folded sheet of strong paper, on the outside of which should be written the natural order, the generic name and the names of the contained species. A collection of dried specimens is termed a herbarium and should be stored in cabinets, or small almirahs, provided

Herbarium.

*Asa Gray's *Botanical Text Book*, Volume I, page 377.

with close-fitting doors and fitted inside with pigeon-hole compartments in which the genus covers are placed and are thus readily accessible for reference. The name of the natural order is placed above the pigeon-holes containing the sheets belonging to that order, while it is sometimes convenient to affix an index of the genera in each pigeon-hole on the inside of the cabinet doors, or a list of the genera may be placed on the top of the sheets in each compartment.

Before examining or preparing sections of dried flowers and fruits they should be placed in cold water and then gradually heated until sufficiently soft.

# PART V.—WOUNDS AND DISEASES.

## Chapter I.—WOUNDS.

143. If a mass of living cells is cut through with a sharp knife, the exposed surface at first turns brown and then becomes covered with a protecting coat of corky tissue. The cells actually cut through die at once, and in consequence of the access of air some of their contents become oxidised, this process causing the brown discolouration. The layer of cork is formed by the uninjured cells immediately below the cut surface which, by their growth and division, give rise to layers of flat tabular cells. These soon die and, their cell walls having become converted into cork, form a protective coat several layers of cells in thickness which, although elastic, is very impervious to air and water, and consequently the rapid drying up and destruction of the living cells beneath it is effectually prevented. This process may be well observed on the cut surface of a potato, although the wounded surface of any mass of living cells, in the root, stem, leaf, or elsewhere, will present essentially the same phenomenon. **Healing of Wounds by means of a Cork Layer.**

144. If the cells below the cut surface are growing and dividing when the cut is made, the first thing which happens is the dying of the actually cut cells and then the external corky coat is formed as before. Now, this thin layer of cork being very elastic, the pressure exerted by it on the living growing tissues beneath it is very much less than was caused by the original external tissues which have been removed by the cut. These living tissues are consequently able to grow far more vigorously than before and they give rise to a juicy cushion of thin-walled cells which is called a *callus*. This at first consists of a mass of embryonic cells; some of these remain capable of growing and forming new cells, thus retaining their character as embryonic tissue, while the remainder become gradually differentiated, very much as is the case in normally growing tissues. This process may be well seen on the vigorously growing stem of a young sapling. Suppose, for instance, that we cut away a longitudinal strip of the external tissues from such a stem, the cut extending down to the wood which is thus left exposed. The wound at first gapes owing to the contraction of the tissues of the cor- **Callus—formation and healing of Wounds by Occlusion.**

tical jacket, which, before the wound was made, was tightly stretched and exerted considerable pressure on the tissues below it. The living cells of the cortex and the cambium at the edges of the wound at once protect themselves with a layer of cork and then rapidly develop a callus as above described, which pushes out towards the surface of the wound, *i.e.* in the direction where there is the least resistance, and thus forms a thick pad-like rim around the wound. A layer of cells in this callus, continuous with the cambium of the stem, retains its embryonic character and acts as a cambium, the tissue formed on the inside of the layer, abutting on the old wood, becoming differentiated into wood and that outside the cambial layer developing into cortical tissue. This wood formed in the callus is called *wound-wood* and, owing to the diminished pressure and abnormal conditions under which it is developed, it usually differs considerably from normal wood in its structure. The cortex of the callus usually remains thin and exerts far less pressure on the tissues beneath it than old cortex would do. These callus cushions may consequently continue to grow very rapidly for several years, and the whole surface of the wound may thus become quickly and completely covered over, owing to the various cushions coming in contact with one another and coalescing. In many cases no thick, outer bark consisting of layers of dead elements has been formed on the callus pads when they thus come in contact, and, as they continue to grow and press against one another, the thin cork layers lying between them are ruptured and squeezed out, while the cambium and living cortical tissues of the adjacent lips come into direct contact and grow together. The cambium of the various cushions thus uniting, a continuous cambial layer is formed over the whole surface of the wound, and then further growth in thickness continues in the normal way as if nothing had occurred, and very soon no external sign of the injury can be seen. If thick layers of dead bark have been formed on the callus when the various cushions come into contact, the complete coalescence of the latter is rendered much more difficult and may be much delayed. In some species the living cells of the medullary rays on the surface of the exposed wood also take part in this healing process and form callus pads, in addition to those developed at the margins of the wound. A wound which is healed in the manner described is said to have been *occluded*, and this healing process is termed *occlusion.*

It must be noted that no growing together, or intimate union, is possible between the living cells of the callus and the dead elements of the wood which were exposed on the wound surface, and, although the callus grows over and is closely adpressed to the wood, the junction between them always remains as a distinct line of separation. This is often well seen in the case of hammer-marks stamped on the exposed wood of a blaze, the latter having been subsequently completely healed over as described above. Years afterwards such a mark may be clearly distinguished deeply embedded in the trunk, the letters and figures having been merely covered over by the new wood and hence not obliterated.

**Bruises.** 145. If, in the above example, the outer tissues of the sapling had been crushed and bruised by a blow from a hammer, or other means, instead of being removed by a clean cut, rapid healing in the manner described would have been impossible. The bruised cambium and cortical tissues die, contract, and remain adhering to the wood below, thus obstructing the formation of a callus by the living tissues bordering the wounded patch. Such wounds in consequence do not heal easily.

**Wounds caused by Pruning.** 146. Now, instead of wounding the stem itself, we will suppose a branch to have been cut off. If the cut has been made just above one or more leafy shoots, the latter will keep the living tissues of the stump alive and the severed end will eventually be healed over by callus tissue. If the stump carries buds, the wound may stimulate the development of these into leafy shoots and the healing process will be as before. If, on the contrary, such a branch stump bears no buds, or leaves, the tissues will dry up and die. The living cambium and cortical tissues of the stem, at the base of the dead stump, now develop a ring of callus tissue around the stump, but the formation of this callus and its further extension up the stump are much impeded by the dead cortical tissues of the latter, which remain adhering to the dead wood and under which the callus has to force its way. The healing is consequently much delayed and the dead tissues of the stump frequently rot before the process is complete, the decay then spreading into the sound wood of the trunk and causing a hollow stem. Hence, in all cases of pruning branches, the latter should be cut off close to the stem, the cut surface being parallel to the surface of the stem, the healing process then being similar to that described for a simple stem wound. In order to prevent decay spreading in

the wood exposed on the surface of the wound, it is important to see that rain water is not allowed to lodge on the wound and that air is excluded as far as possible. In Conifers the wound is often well protected by a copious exudation of resin and in many Dicotyledons gums, to a certain extent, serve the same purpose, but it is always best to cover the cut surface with wood tar, or some other substance, which will not interfere with the process of occlusion and will prevent air, water, and fungus spores obtaining access to the wound until the healing is complete. In connection with artificial pruning may be mentioned the case of the lower branches of trees growing in a dense wood, which are killed by the heavy shade. If such branches are small their wood is usually soft, which soon becomes quite rotten. Such branches in consequence quickly fall or are broken off close to the stem and, the wound soon healing, little harm is done. In the case of larger branches, however, which often contain well marked heart-wood, the dead stumps persist for several years and, as the stem increases in thickness, these gradually become enclosed in the wood of the stem. No intimate union being possible between the dead stumps and the living tissues of the stem which gradually envelop them, such stumps form knots in the wood which may fall out after conversion and cause holes. In addition to being a source of weakness such stumps are usually more or less decayed and may cause wide-spreading decay in the sound wood of the stem.

**Girdling or Ringing.**

147. Killing trees by girdling or ringing is a common forest operation, *e.g.* in the case of Teak in Burma. If a deep circular cut is made in a Teak tree, down to, and into, the heart-wood, thus completely severing the connection between the layers of cortical tissue and sap-wood situated respectively above and below the wound, the tree will quickly die. This is due to the fact that the heart-wood is incapable of water conduction, and hence the transpiring crown of the tree situated above the girdle no longer receives, from the soil, the necessary supplies of water to replace that lost by transpiration and the ultimate death and drying up of all parts above the ring is consequently assured. This, generally speaking, holds good for all trees which possess a well-marked heart-wood. Trees, however, which possess no distinct heart-wood can also be killed by girdling, *e.g.* the Himalayan Spruce and Silver Fir, but in the case of such trees the effect of girdling is frequently very slow, the trees often remaining alive for several years. In such

cases, it is not possible to ascribe the death of the tree to any one single factor. It is known that, as a general rule, the water-current from the roots passes chiefly through the younger external layers of wood, but it must be remembered that all living tissues are more or less capable of water conduction, and that the ascending water-current under ordinary circumstances only makes use of the young wood layers because it can pass through them more rapidly than it could through any other tissue. If a ring-wound through the young wood now interrupts these rapidly conducting channels the water-current is compelled to make use of some other and less satisfactory channels. Girdling may thus result in the water-current being carried through the inner and older wood-rings which, under ordinary circumstances, would not have been utilized, and although this interferes with the rapidity of the current and is thus more or less injurious, the death of the tree may not result from this cause for a considerable period. It should also be noted that the longer the distance which the water-current has to traverse in slowly conducting channels, the greater will be the interference with the rapidity of the current and, consequently, the wider the ring, the more likely it is to be effective in causing the death of the tree. We must, however, consider not only the effect of the wound on the upward water-current, but also its effect on the supply of food materials descending the stem from the leaves. These food substances are mainly carried through the sieve-tubes of the cortex. That the downward passage of these materials is interrupted by the ring-wound is indicated by the fact that a callus often begins to form only along the upper edge of the ring, the severed tissues along the lower edge, which now receive no food supplies from the crown, being unable to produce a callus. Now if the passage of the food materials from the crown to the base of the stem and the roots is thus prevented, it is obvious that although the reserve materials in the tissues of the roots and the base of the stem may for a time suffice for the nourishment of the cambium, for the extended growth of the roots, and for the production of new root hairs and water conducting layers of wood; this cannot continue indefinitely, and if no other source of food materials is made available, the supply of water obtained from the soil by the roots will gradually decrease, and the death of the tree eventually result from this cause alone. That the reserve materials in the roots are thus sometimes exhausted is indicated by the fact that, in some cases, no coppice shoots arise from the stumps of trees which have been killed by girdling, there

being no reserves in the tissues of the stump and roots available for the production of such shoots. If the severed living tissues on the lower edge of the ring receive sufficient nourishment from leafy shoots situated below the ring, they will also proceed to form a callus, which may meet and coalesce with that developed from the upper lip, the wound being thus healed over and the normal continuity of the tissues re-established, although, here again, the wider the ring, the longer will the healing be delayed and the more injurious will be the wound. Cases will be occasionally met with which do not appear to admit of an explanation according to the above facts, and such exceptions will be found due to the existence of special conducting tissue in the interior of the stem, wood which has retained its power of conductivity, internal phlœm, etc. As a general rule, however, the non-success of girdling is due to the operation not having been thoroughly performed, complete interruption of the ordinary conducting channels not having been secured. In some cases it is possible that the failure of the operation is due to the roots of the girdled tree being in intimate connection with the roots of neighbouring trees, and to their thus being able to obtain their necessary food materials from such trees.

**Cuttings.** 148. Now the callus which, as we have seen above, so frequently results from a wound, consists, at all events in the early stages of its development, largely of embryonic cells, *i.e.*, cells which must have the capacity of producing any part of the plant body in which they occur, for the whole plant has been built up by the activity of such cells. Hence it is not surprising that the callus is often found to give rise to roots, and buds capable of developing into shoots. Such roots and buds are termed *adventitious*, as are all structures which occur in places where under normal conditions they would not have been developed. This may be well seen in the case of cuttings, these being shoots which have been separated from the parent plant by a clean knife cut. The base of such a cutting, if kept moist by being placed in soil or damp air, soon becomes covered with a callus developed from the living growing tissues adjoining the cut surface, in the manner described above. Roots then spring from this callus and through the cortex at the base of the cutting, the latter thus becoming an independent plant. It is important to restrict evaporation from the cutting as much as possible until the new roots have been developed, and the cuttings are often first laid slopingwise in the ground and entirely covered with earth with the

exception of the upper buds, until they *strike*, *i.e.* develop roots. The removal of the transpiring leaves from the cutting also, to some extent, serves the same purpose. In India large posts of *Boswellia serrata*, *Erythrina suberosa* and other species which have been placed in village fences may often be seen which have, after the manner of cuttings, developed roots from the base and shoots from the upper end and thus become independent trees.

**Pollard-shoots, Stool-shoots and Root-suckers.**

149. In the case of many species, the felling of the tree results in a more or less vigorous development of callus from the living tissues on the wounded surface in which adventitious buds may arise, while the wound also often stimulates the cambium to form adventitious buds elsewhere on the stump or on the roots. If now there is a sufficient stock of food materials in the stump, or roots, or both, a vigorous development of shoots from the adventitious buds in the callus, or from the adventitious or dormant buds elsewhere on the stump, or from the adventitious buds on the roots, may result. When the young shoots arise on, or close to, the cut surface, the latter is usually quickly covered over by the healthy tissue at the base of the vigorous young shoots and, the access of air and water being thus obstructed, the spread of decay into the stump and root system is prevented. When the stump of the tree is high and the shoots arise at some distance from the ground they are usually known as *pollard-shoots*, whereas if the tree is cut low and the shoots arise close to the ground they are called *stool-shoots*, or *coppice-shoots*, while the shoots springing from the roots are termed *root-suckers*. Root-suckers usually develop young roots of their own, and this often occurs also with stool-shoots which arise at, or near, the surface of the ground. By directly wounding the roots themselves and by thus stimulating the development of callus, and of adventitious root-and-shoot-buds on, and near, it, the production of root-suckers may often be increased. When considering the phenomena here alluded to, care must be taken to distinguish those cases in which the individual plant is merely trying to recover from the severe injury which it has received from those in which a more or less complete process of reproduction may be recognised, consisting in a division of the mother-plant and the establishment of new and independent individuals. The latter, for instance, occurs when root-suckers become independent of the mother-tree and are furnished with vigorous root-systems of their own. The same thing also appears to occur in cases where stool-shoots produce roots of their own which, owing to the rapid disinte-

gration of the old stool, are able to develop vigorously and without obstruction in all directions. In the case, however, of pollard-shoots and frequently also in the case of stool-shoots, there is, correctly speaking, no true reproduction. Here the normal development of the individual tree has received a very severe check, the individual has been badly wounded and injured by the removal of its crown of foliage, and the plant sets about repairing the injury as well as it may, just as we have seen is done in the case of other wounds. Thus the tree at once endeavours to replace the crown of foliage which has been removed by a vigorous growth of pollard or stool-shoots. As a general rule, it appears that the closer the resemblance between the new crown of foliage formed by the young shoots and the old crown of which the tree has been deprived, the better will the new crown be able to fulfil its duty in providing for the healthy maintenance and extended growth of the old root-system, *i.e.* the more perfect will be the tree's recovery. In other cases the process of recovery is slower and appears to resemble in a general way that exhibited by a tree, the crown of which has been severely damaged by drought or frost. In such a case, if the injury has not been too severe, young shoots appear on those portions of the stem and branches which are still alive. These grow and gradually take the place of the dead branches which ultimately fall off, and in a few years the recovery may be so complete that we can see no signs of the damage remaining. A very similar process often takes place in the case of a tree which has been pollarded or coppiced; the young crown of foliage being unable to supply sufficient food material to the old roots, many of the latter begin to die back from their tips, while a crop of young roots is adventitiously developed from those parts of the old roots which still remain alive. The tree, as it were, appears to be trying to start life again with a new crop of shoots and young roots. Just as a tree may completely recover from severe damage by frost, drought, or other injuries, so may it also satisfactorily recover from the injury inflicted by coppicing or pollarding, but it should be remembered that any demand made on the powers possessed by a plant of recovering from an injury is usually very harmful if *repeated*, and in Europe experience has shown that if ash or maple are repeatedly cut over they often die after the second or third operation.

**Propagation by means of Layers and Guti.**

150. Propagation by means of *layers* and by *guti* are operations often resorted to by gardeners in India in preference to propagation by cuttings, they being as

a rule more certain of success. Layering is described as follows by Firminger: "Select a branch of ripened wood of the plant to be layered, that will bear being bent down to the earth without breaking. Cut the branch half through with a sharp knife just under one of the leaf buds towards its extremity and then pass the knife upwards, so as to slit the branch about an inch or two up. The slit-piece, with the leaf-bud at its extremity, called the 'tongue,' should be kept open by inserting a small piece of tile. Remove the earth to the depth of two or three inches from, or place a flower-pot over, the spot just where the tongue falls on the branch being bent down; then carefully bend the tongued part of the branch into the earth, or into the flower-pot; secure it in that position by a peg, and cover it over with earth, which should be pressed down and watered.*" A callus is developed from the cut surface of the tongue from which roots arise just as in the case of cuttings, but the layer differs from a cutting in that it receives supplies of water and salts in solution through the wood of the unsevered portion of the branch. So soon as the layer has developed its own roots and thus become independent of this source of supply, it may be completely severed from the parent plant. The operation may be hastened by making a half-ring wound on the unsevered half of the branch down to the wood. The food materials descending from the leaves of the layer which would have passed down to the parent plant along this half of the branch are thus intercepted and are also devoted to the production of callus and new roots.

The operation known as *guti* consists in completely ringing a branch down to the wood, the latter being carefully scraped to insure the removal of all the cambium and cortical tissues. The wound is then covered with a lump of adhesive earth or moss which is maintained in position by a bandage and kept moist. Here the passage of the water current along the young wood of the branch is not interrupted and the leaves are enabled to manufacture food materials vigorously; these materials passing down the sieve tubes in the cortex are intercepted in their course at the upper edge of the ring where they are devoted to the production of a callus and new roots. So soon as the latter are well developed, the branch may be completely severed from the parent and an independent plant is produced. *Ficus elastica* is frequently propagated in this way.

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* *A Manual of Gardening for Bengal and Upper India* by Thomas A. Firminger, 3rd edition, 1874, page 81.

Grafting. 151. When describing above the occlusion of wounds it was noted that the cambium and living tissues of one callus cushion, coming into contact with those of another cushion, coalesced with, and became intimately united to them. This power possessed by living tissues of thus growing firmly together is taken practical advantage of in several ways in the operations known collectively as *grafting*. Ordinary grafting consists in bringing the cambium and living tissues of one plant into close contact with similar tissues of another plant. These ultimately coalesce, and from the union of parts of two distinct plants we thus get a single plant; one of the partners, called the *stock*, which was provided with roots, supplying water and mineral salts from the soil, the other partner called the *scion*, which possessed shoot buds, supplying food materials which it manufactures in its leaves. Such a union is, however, as a rule, only possible between closely related plants. In the majority of cases of successful grafting each partner is found to preserve its own individual characteristics; if one of them naturally grows faster than the other it continues to do so after grafting has taken place and a distinct line of demarcation between the fast-and slow-growing tissues of the partners is visible in the stem of the plant resulting from the grafting; similarly an Alphonse mango grafted on an ordinary country-mango stock, continues to produce Alphonse mangoes as before and not the unpalatable country fruit. At the same time rare cases are known where grafting has resulted in more or less altering the characteristics of the partners. The method of grafting usually adopted in India is that known as *inarching*. Firminger describes the operation as follows: "Procure a seedling of about one or two years old, of the plant to be inarched, or where a seedling is not to be obtained, a rooted cutting of the same age, of the plant that is to supply the stock. Put it in a pot, and when it is well established it will be ready to be operated upon. Slice away from one side of the young stem a piece of bark, with a thin layer of the wood beneath it, about two inches long; do the same to a young stem of the plant to be inarched from, and then bring together the two stems that have thus been operated upon so that the cut parts lie close in contact face to face, and bandage them with cotton-twist. In course of time, when the parts have united, head down the stock and dissever the scion from the parent plant by cutting it through below the bandage. The grafted plant must then be put

somewhere in a shaded place and not removed from its pot till it has made a vigorous growth, and stock and scion have become thoroughly incorporated." *

This operation of inarching is often performed naturally, and it is not uncommon to find branches of trees which, after pressing and rubbing against the stems and branches of neighbouring trees, have become joined to them at the points of contact. This is even more frequently the case with roots, and such natural root grafting probably explains some cases of failure in ringing trees and instances of stumps producing coppice shoots which, as a rule, are unable to do so.

152. *Budding* is another variety of grafting which is commonly practised. This must be carried out when the sap is up and is best done just before the period of vigorous growth. A T-shaped cut is made in the cortex of the stock down to the wood. A piece of cortex, called the "shield," bearing a healthy stout bud is detached from the wood of the scion and inserted in the T cut, the latter being then bound round tightly with cotton-twist or other bandage. The inside of the shield thus lies closely against the wood of the stock and the bud projects through the slit in its cortex. One or several buds may be thus grafted on the stock, and when these have developed vigorous shoots, the branches of the stock are cut back close above the budded shoots, so that the water-current from the roots may not be diverted from the latter. **Budding.**

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* *Op. cit.*, pages 84-85.

## Chapter II.—DISEASES.

### Section I.—Introductory Remarks.

Duration of Plant Life.

153. So far as we know at present, all the embryonic tissue of plants, such as the cambium, which has not become converted into specialised tissue or organs, is capable of unlimited life, providing the external conditions are such as to allow of its growth. The continued existence of plant life upon the earth in fact depends on this property of embryonic cells. Thus bacteria, the cells of which all retain their embryonic character and power of continued growth and of producing new individuals, possess within themselves the power of unlimited life. In annual plants the death of the plant ensues on the production of the seed. The seeds, however, contain embryonic cells, and the continued existence of the latter renders the maintenance of the species possible. Trees, on the other hand, owing to the presence of the embryonic cambium, are often capable of living for very long periods and may reach an age of more than 1,000 years. In a tree considerable portions continually die in the ordinary course of natural development. Thus the root-hairs only live for a short time, large quantities of wood are killed to form heart-wood, masses of external tissue die and become dead bark, the leaves live for a few years only at the longest, sepals, petals and stamens have a very brief life, so that in an old tree the actually living tissue which has arisen from the embryonic cambium and become converted into special tissue, or organs with a particular function to perform, is at most but a few years old. Not only in annuals, but in some plants which do not flower for several years, such as some species of *Strobilanthes*, *Bamboos* and some *Palms*, the production of flowers and seed causes such exhaustion of the plant's vitality that death ensues. In some cases it has been found possible to prolong a plant's existence by artificially preventing the production of flowers, and cases are known in which annuals have thus been made perennial. Whether on account of internal or external causes, however, so far as we know at present, every individual plant does sooner or later die.

Definition of Disease.

154. In nature the development of every organism depends on the number and intensity of the injurious and beneficial influences, not only of other organisms, but also of the non-living environment, which affect its develop-

ment. Only when all the factors which influence the development of an organism combine to act in the most favourable way can an ideally *healthy* development become possible. In nature, however, this is probably never realized, except perhaps for very limited periods in the life of any particular organism, and, with the gradually increasing predominance of injurious over beneficial factors, we get at first a condition which we recognise as *disease* and eventually death. Seeing, however, that an ideally healthy development, for even limited periods in the life-history of any particular organism, is rarely, if ever, possible, it is obviously very difficult to define exactly what we mean by disease. We have seen that the ordinary course of the normal development of a plant in itself necessitates the death of considerable portions of the plant-body, or even of the entire plant in cases where death naturally follows the production of flowers and seed, yet here we can hardly speak of disease. For practical purposes, however, we may regard as diseased any condition of the plant, or of any part of it, which, unless ameliorated, will lead to the obviously *premature* death of the plant, or of some part of it.

155. In *Part IV* above, it has been noted that what we call the struggle for existence is responsible for the premature death of organisms, and that every organism, in order to maintain itself, has to struggle with other living organisms and to fight against such factors as unfavourable climate, excessive heat and cold, drought and so on, see p. 148. When it is considered that these factors affect various organisms in very different ways, we begin to realize how complex the relations are which bind together the organic world. Hence when studying the diseases of a particular plant, we must not only consider the effect exercised upon it directly by such factors as soil, moisture, temperature, light and such like, but we must also discover how other organisms, plants as well as animals, affect it, what factors influence the development of all such correlated organisms, and in what way. To illustrate how two organisms, between which at first sight we should say there was absolutely no connection, may be dependent on each other for their existence, we cannot do better than take the following well-known example given by Darwin :— Struggle for Existence.

"Humble-bees alone visit red clover, as other bees cannot reach the nectar. * * Hence we may infer as highly

probable that, if the whole genus of humble-bees became extinct or very rare in England, the * red clover would become very rare, or wholly disappear. The number of humble-bees in any district depends in a great measure upon the number of field-mice, which destroy their combs and nests. * * Now the number of mice is largely dependent, as everyone knows, on the number of cats. * * Hence it is quite credible that the presence of a feline animal in large numbers in a district might determine, through the intervention first of mice and then of bees, the frequency of certain flowers in that district!"* We frequently do not realize the severity of this great struggle for in nature a balance is generally maintained between the conflicting forces, a position of more or less stable equilibrium being eventually arrived at, which, however, a very trifling circumstance may entirely upset. The plant known as *Lantana aculeata* is a native of America and was introduced into Ceylon about 1824. Since then it has spread with extraordinary rapidity over the Peninsula of India, where it "now covers, with a dense network of intertwined branches, large areas of country, almost to the complete exclusion of other vegetation."† This well illustrates how a plant, the development of which is favoured more than is that of other species by the factors of the locality, soon succeeds in eliminating all other vegetation. Again man, by forming pure forests of a single species of tree, has favoured the development of the insects and fungi which prey upon it, by collecting together and making easily accessible for them masses of their favourite food, a procedure which more than once has led to the total destruction of extensive forests in Europe, while in the teak forests of India we clearly see how much more damage is done in pure forests than in mixed by defoliators, such as *Hyblaea puera* and *Pyrausta machoeralis*.

Factors which influence the Relations existing between Organisms in Nature.

156. Let us now try to realize the factors which induce one organism to injure or help another and which enable it to do so, as well as the conditions which enable life to still continue on the earth amidst so much destruction.

Complex carbon compounds generally known as organic materials form an essential part of the food of all living organisms. Green plants alone among all living organisms

* *Origin of Species.* By Charles Darwin, 6th Ed., pages 53—54.
† *A Manual of Indian Timbers.* By J. S. Gamble, 1902, page 524.

(with a few rare and unimportant exceptions) are able to manufacture their organic food from the carbon dioxide of the air; all other plants and animals must obtain their carbonaceous food from materials which directly, or indirectly, have been manufactured for them by green plants. Without green plants then all life on the earth would eventually cease. These organic compounds contain energy, or in other words capacity for doing work, and they can be made to yield up this energy which is stored within them for the use of living organisms, in various ways. Some of them, for instance, such as wood and coal, when burnt in a fire are made to give up their energy in the form of light and heat. Others can be used as food and made to give up their energy in the process known as respiration. Whether these substances are slowly burnt off in living organisms as food, whether they are quickly consumed in a fire, or whether they are slowly oxidised and disintegrated under the chemical and physical actions of air and water, the end product of the decomposition is carbonic dioxide. Now when green plants first construct these organic materials large quantities of carbon dioxide are removed from the air; a certain amount of this is again returned by mankind and animals by utilising organic matter as food or fuel. Large quantities of carbon, however, still remain locked up in the dead bodies of plants and animals which have not been utilised in this way, and if these dead bodies were to remain unchanged, the available supply of carbon dioxide in the air would eventually become exhausted and all living beings would be driven out of existence. We know, however, that this is not the case, but that all such dead remains rot, decay, or putrify, and are eventually broken up into the elements of which they were formed, carbon dioxide being again set free. Ordinary oxidation, as already mentioned, is responsible for a certain amount of this decomposition, but we now know that living organisms (especially bacteria and fungi) which derive their carbonaceous food from these dead bodies take an exceedingly active part in this work and are hence indispensable for the maintenance of life. Plants which thus derive their carbonaceous food from the dead bodies of other organisms, or from substances manufactured by other organisms, are termed *saprophytes*. They Saprophytes. do not obtain their supplies directly from the living tissues of an organism. Green plants then, we see, are continually building up organic matter and thus not only provide a continual supply of food for animals and other plants but also prevent the accumulation of poisonous quantities of carbon dioxide in the

air; non-green plants and animals, on the other hand, are continually consuming organic matter and by returning carbon dioxide to the air keep up the supply of raw material necessary for the manufacture of fresh organic material by green plants. From the fact that the average percentage of carbon dioxide in the air remains practically constant, we see that a balance is maintained in nature between this work of construction on the one hand and of destruction on the other, a continuance of life being thus assured.

We may then divide all living organisms into the following two great classes:—

(1) *Green Plants* obtaining their carbonaceous food from the air.

(2) *Non-green Plants and Animals* obtaining their carbonaceous food directly or indirectly from green plants.

Now although, as has been shown above, each of these great classes as a whole depends upon the other for its existence, yet we know that in nature individual organisms, owing to their great powers of increase and to the limited quantity of food materials available, are continually being injured and destroyed in the struggle for existence by other organisms. Regarding their relations then to any particular organism or group of organisms, all others may be classed as follows:—

Competitors.

(1) *Competitors.* Those which are indirectly injurious owing to their competition for the same necessaries of life.

Parasites.

(2) *Parasites.* Those which are directly injurious owing to their obtaining some or all of their necessaries of life directly from the living bodies of organisms. The organism from which a parasite obtains its supplies is called a *host.*

Symbionts.

(3) *Symbionts.* Those which not only are not injurious but are actually beneficial and are hence more or less necessary for the existence of the organisms benefited.

Symbiosis.

The phenomenon of two organisms living together with benefit to one or both of them is termed *symbiosis.* If both organisms are benefited it is called *reciprocal symbiosis*; if only one organism is benefited it is called *antagonistic symbiosis*, as in the case of a parasite and its host. Symbiosis also may be *close* when the organisms live in intimate connection with each other, or *distant* when there is no direct or fixed union between them. It is of course often impossible to insist on these distinctions; organisms, which at one period of their life may be beneficial (symbionts), at other times may be

directly injurious (parasites), and in cases of close symbiosis it is often difficult to decide whether or not one organism is slightly injured by the other, that is, whether they are to be regarded as reciprocal symbionts, or as parasite and host.

**Symptoms of Disease.**

157. The symptoms which indicate a diseased condition are of course very various according to the different factors at work and may consist of unusual pallor of the leaves, discoloured spots or blotches on the leaves, premature death of leaves, or branches, and so on. At the same time such symptoms in themselves by no means necessarily indicate the factors which are responsible for the disease. Premature death of twigs and branches may, for instance, be due to the effects of fire, frost, drought, an unfavourable condition of the soil or the attacks of scale insects.

**One Factor alone is rarely responsible for a Disease.**

158. In some cases the direct connection between the injurious factor at work and the diseased condition of the plant produced by it is obvious. We may, for example, see a larva directly feeding on and destroying the leaves, or we may notice that the death of our tree follows immediately after an unusually severe frost, and in such cases it is natural to conclude that in the absence of the larva or frost the disease would have been avoided. At the same time from what has been said above regarding the struggle for existence it will be realized that one factor alone is rarely responsible for a disease and this may frequently be the case even in such apparently obvious examples as the above. The destructive larva, for instance, might not have harmed our trees if the weather or some other factor had not favoured its development to an unusual extent, the frost might not have injured our trees if they had not been growing in a damp valley, their twigs in consequence having remained soft and full of watery sap instead of becoming lignified and matured like those of the trees on the hills around. The discovery of one obviously injurious agent at work is thus by no means necessarily a satisfactory conclusion to the investigation of any particular disease. In cases where we have not ourselves been able to note the first appearance of a disease, it is of course most important to ascertain, as far as possible, the character of the first visible symptoms, the time when they were seen, and whether the existence of any unusual external influence, such as severe drought, the occurrence of a fire, etc., was noticed when the disease first appeared.

Knowledge necessary for a successful Investigation of Plant Diseases.

159. In order that our study of the diseases of our forest plants shall be of practical value, we must by careful observation and study :—

(1) Be able to recognise the first symptoms of a diseased condition. This among other things necessitates a knowledge of the life-history of our plants. We should, for instance, be inclined to ascribe such phenomena as the annual dying back of the seedlings of bamboos and other species, or the shedding of shoots of some species of *Strobilanthes*, to a disease, if we did not know that these are necessary in the ordinary course of the plant's development.

(2) Be able from these symptoms to at once form an approximate idea as to the nature of, at all events, some of the principal factors causing the disease.

(3) Be acquainted with, and know the mode of action of, all important factors which either beneficially or injuriously affect the normal development of our plants. This will then enable us to discover in any given case of disease any unusual absence of beneficial factors or presence of injurious influences and, while thus indicating the principal factors responsible for the disease, will help us in deciding on the most advisable remedial and preventive measures.

(4) Be acquainted, as far as possible, with the life-histories of plants and animals which are capable of benefiting, or of injuring, our forest plants and with the factors which influence the development of the same, so that we may be able to take measures for their destruction, if injurious, or for their advantage, if beneficial.

Sub-division of the Subject.

160. A detailed account of the life-histories of the various animals which influence the development of forest plants, their mode of action, the symptoms by which the diseased conditions caused by them may be recognised, together with an account of the measures to be taken for their destruction, or advantage, form the subject of Forest Zoology. It is, however, interesting to note that several cases of symbiosis between plants and animals are known. Insects, for instance, effect the pollination of flowers in return for nectar or pollen received from the flowers, birds and other animals disseminate seeds in

return for food in the shape of fruit, etc., while some ants in return for food provided by the plant protect the latter against other injurious insects.

The following sub-divisions of the subject will now be considered in detail :—

Influences of other Plants on plant development.
Influences of the Soil on plant development.
Influences of the Atmosphere on plant development.
Effect of fire on plant development.

## SECTION II.—INFLUENCES OF OTHER PLANTS ON PLANT DEVELOPMENT.

161. Following the classification proposed above, we will consider, in order, the effect exercised by plants in their capacity as (*a*) Competitors, (*b*) Parasites, and (*c*) Symbionts.

### (*a*) *Competitors.*

162. We have to consider here not only the competition among roots for the water and mineral salts in the soil, but also that among shoots for the sun-light and air. In so far as competition with the higher plants above ground goes, their insignificant development in the air renders the Cryptogams of little or no importance, but in the soil their competition may be injurious. The mycelia of many saprophytic fungi, for example, are known to compete actively with the root hairs of higher plants in the soil by taking up large quantities of valuable mineral salts, especially of phosphorus and potassium. The most injurious competitors with the higher plants, however, are undoubtedly to be found in the ranks of the higher plants themselves, *i.e.* among the Phanerogams. This subject has already been alluded to in *Part IV* above, see p. 148, and only a few striking examples of competition can be mentioned here. Plant Competitors.

In the mixed forest of Deodar and Blue Pine in the Western Himalayas, the latter has continually to be girdled to prevent its suppressing and ousting the more valuable Deodar. A similar state of things exists in all our Indian mixed forests and the forester has to girdle, or fell, trees which, as yet, are of no value to prevent their vanquishing the better kinds in this competition for the necessaries of life. Deodar and Blue Pine.

Another well-known case of competition is afforded by the relations existing between Teak and various gregarious species of bamboos. In Burma, for instance, the dense shade afforded by the gregarious *Bambusa polymorpha* often effectually Teak and Bamboos.

prevents the establishment of any Teak reproduction beneath them. Even when such seedlings have become established during the gregarious seeding and dying back of the bamboos the young trees may still be caught up and suppressed by the young bamboos resulting from the general seeding.

Trees and Grasses.

In areas which have been cleared for cultivation in our forests and then abandoned, the dense growth of grasses which quickly takes possession of the ground often prevents for many years the re-establishment of tree-species. The mass of grass to some extent prevents the tree seeds from reaching the ground, the dense network of grass roots intersecting the superficial layers of soil in all directions have got the start in the competition for water and mineral salts and compete with the delicate roots of the few seedling trees which may have germinated, while the heavy growth of grass above the ground effectually prevents the struggling plants from obtaining the light and air indispensable for their development.

Trees and *Strobilanthes*.

Similar in many respects, with regard to their effect on the development of other plants, are some species of *Strobilanthes*. The stems of the gregarious *S. Wallichii* in the Western Himalayas, for instance, " form a dense matted covering to the soil, and prevent the seeds of the forest trees, chiefly oaks like *Quercus dilatata* and *semecarpifolia*, and firs like *Picea Morinda* and *Abies Pindrow*, from reaching the ground, or if they do reach the ground, obtaining sufficient light for germination and growth."*

Climbers.

163. Climbing plants again are often very injurious competitors of which our forests contain many examples, the most striking perhaps being the well-known *Bauhinia Vahlii*. The damage done by such plants consists chiefly in the injurious competition for light between their foliage and the crowns of the trees on which they climb. The species mentioned, for instance, climbing to the tops of the highest trees, eventually envelops them with its mantle of enormous leaves which sometimes measure as much as 18 inches across. The dense curtains of its foliage effectually prevent the access of light to the tree branches covered by them, and the leaves on the latter being unable to manufacture food, the tree is ultimately starved. The roots of such climbers also are more or less injurious by competing in the soil with the roots of the plants on which they climb for water and mineral salts. Moreover, the pressure exerted by the coils of woody climbers on the thickening stems and branches of the plants

* *Manual of Indian Timbers* by J. S. Gamble, 1902, p. 519.

supporting them more or less interferes with the descent of food materials from the leaves in the tissues of the cortex and consequently with the nourishment and growth of the cambium. The latter may be thus killed in places and the stems or branches become deformed and irregular, often assuming a corkscrew shape owing to the growth in thickness taking place in a spiral direction. It is, indeed, not uncommon to find dead stems which have been effectually girdled by such climbers.

164. This brings us to a consideration of the effect of so-called *epiphytes* on other plants. The student must be careful not to confuse the term epiphyte with that of parasite. An epiphyte is a plant which grows on another plant, the term having reference merely to *position* and thus serving to distinguish plants which grow on other plants, from those which grow inside other plants (*endophytes*), or on the earth (*terrestrial*), or in the water (*aquatic*). The word parasite, on the other hand, refers essentially to the manner in which the plant obtains its food, and an epiphyte in consequence may or may not be also a parasite. We often see a young Banyan (*Ficus bengalensis*), or Pipal (*Ficus religiosa*), growing on the top of a large Mango or other tree. Year by year the fig grows bigger and, as its dense crown of foliage develops, it shades the Mango leaves more and more from the sunlight. The Mango then begins to languish, and ultimately dies. After several years an enormous fig tree alone is to be found on the spot and no sign remains of the Mango on whose branches it first started life. If we carefully watch the development of such a fig we find that the young plant sends out its so-called ærial roots which rapidly spread downwards in all directions along the branches and stem of the tree attacked towards the soil. These become woody and frequently become grafted together at points where they come in contact with one another, thus forming a tightly-fitting, latticed, woody mantle over the attacked stems. These roots also produce from their under-surface small absorption-roots which, being negatively heliotropic and positively hydrotropic, cling tightly to the bark and penetrate into its dark cracks and fissures where moisture and small quantities of dust and humus accumulate. The latticed roots themselves also provide lodgment places for dust and organic débris, and from this alone do such epiphytic roots derive their nourishment, for they do not penetrate the living tissues of the stem on which they grow. If such roots are torn away from the stem enveloped by them, it is surprising what a large quantity of dust and earthy matter may often be found

Epiphytes.

adhering to them. When these ærial roots eventually reach the ground they branch therein and rapidly develop a wide-spreading root-system in the soil. If by this time the death of the tree attacked has not been caused by the competition of the fig's crown of foliage, the competition of the fig roots in the soil now help in effecting this result, and the fig with its own root-system established in the soil no longer requires the help of its first support. Many epiphytic species of *Ficus* are thus capable of destroying our forest trees, and it is interesting to note as an historical fact that the famous Banyan "in the Calcutta Botanic Gardens began life as an epiphyte on a wild date-tree of which all trace has long disappeared."* This tree is said to have been about 100 years old in 1886, with 232 supporting trunks developed from ærial roots. The circumference of its crown was then 857 feet, and it was growing vigorously.

Although they are not competitors in the sense here ascribed to the term, the fungi belonging to the genus *Meliola* deserve mention here as injurious epiphytes. As has already been mentioned in *Part IV* above, these minute plants growing on the surface of the leaves of trees and shrubs, and feeding on the sweet juices excreted by insects cover the leaves with black incrustations which, by preventing the access of light to the green chlorophyll, are more or less injurious, see p. 133.

Here also may be mentioned the Lichens which are so often found growing on the stems and branches of trees. A luxuriant growth of lichens is primarily an indication of a moist atmosphere and also frequently of very slow growth in the trees on which they are found, for quick growth combined with the rapid ex-foliation of the outer layers of bark prevent the establishment of a vigorous growth of lichens. In so far as direct injury is concerned the latter are usually of very little importance, their injurious action being apparently confined to interference with the access of oxygen to the living tissues through the lenticels.

(*b*) *Parasites.*

165. The most injurious plant parasites are undoubtedly to be found among the Fungi, of which only a few typical examples can here be considered in detail, *viz.* :—

(1) *Phytophthora infestans.*
(2) *Fomes annosus.*
(3) *Trametes Pini.*
(4) *Puccinia graminis.*

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* *Flora Simlensis* by Colonel Sir Henry Collett, page 459.

166. This fungus belonging to the great group of the *Phycomycetes* causes the most virulent disease from which the potato plant (*Solanum tuberosum*) is known to suffer, and in countries where potatoes are extensively grown the damage done by it not infrequently amounts to a national calamity. In Ireland, for instance, one of the worst famines of modern times has been caused by this disease, and again in 1879 the loss occasioned by it in that country was estimated at nearly £6,000,000. Up to the present the disease in India has been chiefly confined to the moister localities such as Assam, the Eastern Himalayas and the Nilgiris, and experience in Europe has shown that an exposure of 4 or 5 hours to a *dry* heat of 104° F. is fatal to the fungus. From the fact, however, that the disease has of recent years established itself also in the plains of Bengal it appears probable that it will gradually spread throughout the country wherever potatoes are cultivated. This fungus is also known to attack the tomato (*Lycopersicum esculentum*) and a few other plants belonging to the *Solanaceae* and *Scrophulariaceae*.

(1) *Phytophthora infestans.* De Bary.

Species attacked.

The presence of the disease is usually first indicated by the occurrence of brown patches on the leaves of the potato plants. These increase in size and depth of colour, coalesce with neighbouring patches, and gradually extend over the whole leaf surface. Similar patches often occur also on the petioles and stem. The attacked leaves eventually shrivel up and drop off leaving the bare stalks standing, or the leaves and stalks are completely converted into a rotten mass which emits a characteristic and disagreeable odour. This latter is chiefly due to the decomposing action of bacteria on the tissues which have been killed by the fungus. The extension of the disease is particularly rapid in damp warm weather.

Signs of the Disease.

If one of the attacked leaflets is now turned over and one of the characteristic brown patches on the under surface examined with a lens, a number of pale silky threads will be seen standing up from the leaf surface at the edges of the dark spot, thus producing a characteristic pale mouldy margin to the patch which is particularly noticeable in damp weather. See *Plate XVI* (*1*). These more or less erect threads are the ærial hyphæ, or *conidiophores*, of the fungus which have been sent out singly or in tufts through the stomata on the under surface of the leaf for the purpose of bearing the *conidia*, or asexual reproductive organs. These fine tubular conidiophores are branched, and at the tip of the main filament and of each of its branches the minute egg-shaped conidia are produced

Life History and Damage done.

which, if sufficiently numerous, appear as a fine white powder through the lens. The conidia usually fall off or are blown off by the wind almost as soon as they are formed, small swellings in the hyphæ indicating the places where they originated. See *Plate XVI* (*2*). The mycelium or main body of the fungus consists of a branched net-work of fine tubular hyphæ which spread and branch in all directions in the intercellular spaces of the leaf-tissue. If a single hypha is examined with the microscope it will be seen to consist of a long tube, with a transparent thin wall of cellulose, containing water, protoplasm and other substances. The hyphæ are, as a rule, not septate, but transverse partition walls are occasionally developed at irregular intervals to separate the parts of the hyphæ which are still growing and full of protoplasm from those which have completed their growth and are empty. These hyphæ push their way between the cells of the leaf, and as a rule do not directly enter the cells. Occasionally, however, they develop small branches which dissolve their way through the neighbouring cell-walls by means of an enzyme which they secrete, and which, acting as absorbing organs, are called *haustoria*, or suckers.

Whether the hyphæ enter the cells or not, however, the result is the same; they consume a quantity of the oxygen and water which is required by the living leaf-cells, they directly absorb the products of assimilation which would ordinarily have been devoted to the development of the tubers, and finally they destroy the living protoplasm and kill all the living cells with which they come in contact. The cell-walls turn brown wherever the hyphæ touch them, the colour extending for some distance along the walls beyond the actual point of contact. Here and there the ends of the hyphæ emerge from the leaf tissues and develop the branched conidiophores as above described. The conidia being very minute and falling rapidly are blown about and distributed by the wind like fine powder, thus enabling the fungus to spread rapidly and infect fresh leaves and plants.

The conidia may germinate in one of the three following ways:—

(1) If the conidium falls into a drop of rain or dew the protoplasm divides into from 6-16 parts, the tip of the conidium dissolves, and these little masses of protoplasm escape. These are called zoospores, and each is provided with two very fine hair-like appendages called *cilia* which lash the water and enable the zoospore to swim and move about in the water. In a quarter of an hour or so these zoospores lose their

cilia and come to rest. Each then develops a very fine tube which grows out into a hypha. The latter dissolves its way into the cells of the leaf, or stalk, among which it then grows and spreads and soon reproduces the mycelium above described. See *Plate XVI* (3)-(6).

(2) The conidium instead of forming zoospores itself puts out a germ-tube which directly enters the plant tissues and forms the mycelium. See *Plate XVI* (7).

(3) The conidium forms a germ-tube as before, but this instead of entering the plant tissues forms a secondary conidium at its apex which in its turn falls off and gives rise to zoospores or to another germ-tube which directly enters the plant-tissues.

The first of these processes is the most frequent especially with conidia which come in contact with water shortly after falling. Conidia lose their power of germinating in about three weeks, and dry weather is unfavourable to their production and germination. Conidia which are washed by rain upon tubers can infect the latter directly, the germ-tube penetrating the tissue and forming a mycelium there. The mycelium may also pass down the potato stalks and infect the tubers in this way. The mycelium having reached the tubers may proceed to destroy them in the same way as the leaves, the numerous bacteria in the soil assisting in the decomposition of the diseased tissues, or the mycelium may remain in the tubers in a dormant condition. Such infected tubers on being cut open usually exhibit dark patches and when stored frequently rot. If infected tubers are planted out the next season the mycelium again becomes active and growing along with the young shoots sent out by the tuber reproduces the disease.

Preventive Measures.

The plants may be sprayed with Bordeaux mixture which has been described as " the most effective and cheapest fungicide known ". This does not poison the tubers or make them unfit for consumption, but it kills the conidia and zoospores and prevents their germination. In addition to its action on the fungus this mixture has actually proved beneficial to the potato plant and results in an increased yield of tubers. The copper in the mixture in some way which is not clearly understood increases the amount of chlorophyll in the leaves and consequently the assimilating powers of the foliage.*

Care must be taken not to use infected tubers for seed.

* For instructions regarding the preparation and application of Bordeaux mixture see *Potato Diseases of India* by Dr. E. J. Butler, published in the *Agricultural Ledger*, 1903, No. 4, pp. 108-109.

Some varieties of potatoes have been found to resist the disease better than others. Tubers, for instance, with exceptionally thick skins offer more resistance to the entrance of the hyphæ than do others with thin skins. In order to keep up the power of resistance of the potato plant to the disease, care must be taken to always select the most resistant tubers for continued cultivation, and to raise new and stronger varieties from the seed obtained by crossing good, selected, varieties. Diseased stalks, leaves and tubers should be burnt and, to prevent risk of infecting sound tubers from living conidia lying on the ground, the tubers should not be raised for three weeks after the complete dying down of the plants.

As moisture favours the development and spread of the fungus, wet localities should be avoided as far as possible. Irrigation of the crop should be carried out with caution, and the tubers should be stored in a dry well-ventilated place.

Phytophthora omnivora.

167. Very closely allied to the above fungus is another named *Phytophthora omnivora* De Bary, which in Europe has proved very destructive to the seedlings of forest trees. It is probable that the "damping off" of seedlings in many of our forest nurseries in India will be found to be caused by it or by some other nearly related fungus with an almost identical life-history and mode of attack. The first signs of attack are usually dark spots on the stem, cotyledons, or first leaves of the seedling, and if the weather is warm and damp the young plant is soon destroyed. Frequently only the "collar" is attacked and the seedlings then fall over. If only the upper leaves are attacked the seedlings may recover. The damage gradually spreads from one seedling to those around it, and the circle of diseased plants gradually spreads outwards from the centre. The growth and injurious action of the mycelium of this fungus in the tissues of the attacked plant are almost precisely similar to those of *P. infestans*, except that the hyphæ more commonly absorb their nourishment by means of haustoria. The most important point of difference between them consists in the fact that this species produces sexual resting spores (*oospores*) in the tissues of the attacked plant. These spores have the power of remaining dormant for several weeks or months before germinating and hence their name of resting spores. In the formation of these spores the end of a hypha swells up into a rounded knob, and the protoplasm inside it forms into a ball thus producing what is called the *oosphere* or egg-cell. The end of another hypha then coming in contact with the swelling, sends out a small

tube which pierces the cell wall and penetrates to the oosphere, the protoplasm of the hypha then passing into and mixing with that of the oosphere, through the short connecting tube. The oosphere is then said to be fertilized and is called the oospore. These spherical oospores soon develop a hard protective cell-wall and are capable of retaining their vitality and power of germinating for a considerable period. These spores find their way from the decaying tissues of the seedlings into the soil and, if seed is sown in the same soil, the new crop of seedlings is almost invariably severely attacked by the disease, the oospores in the soil germinating and producing hyphæ which then proceed to branch and form conidia as before. This fungus is as a rule only destructive to seedlings, young plants one year old and upwards being rarely injured. It is also capable of living in the soil for a long time as a saprophyte and thus can exist independently of seedlings, although it is always ready to resume its parasitic mode of life on any suitable seedlings it may meet with.

As in *P. infestans* moisture favours the spread and development of the pest; consequently shading the seed beds is inadvisable as this would prevent the rapid evaporation of moisture. Spraying with Bordeaux mixture will aid in preventing the spread of the disease. Isolated specimens of diseased seedlings should be carefully removed and burnt, care being taken not to infect fresh seedlings by shaking off the conidia. If a considerable number are affected the best way of preventing the dispersal of the conidia is to cover the patch carefully with soil. People passing through the seed-beds may convey the conidia on their clothes, or boots, to healthy individuals which should be avoided as far as possible. Seed-beds must be frequently inspected so that timely measures may be taken to check the disease. A seed-bed which has been attacked should not be used again for seedlings of the same species. In some cases good may be done by burning rubbish on the infected seed-bed, sufficient heat being produced to kill the spores in the soil.

(2) *Fomes annosus* Fries.

168. This fungus is also known by Hartig's name of *Trametes radiciperda.* In Europe it has been found to attack *Pinus, Picea, Abies, Juniperus, Thuja,* the Beech, and other dicotyledonous trees. It is most destructive to conifers, and in India it is at present best known on account of the damage done by it to the Deodar, *Cedrus Libani* var. *Deodara,* which it attacks and kills. The fungus is frequently seen in the forests of Jaunsar.

Species attacked.

Signs of the Disease.

Young Deodar trees 6-15 feet in height are chiefly attacked. One tree generally dies first and then the disease spreads to others near it, gaps being formed which quickly extend centrifugally. Resin at first begins to exude from different points along the stem and then the needles turn yellow and fall off. Stems usually take two years to die completely.

Life-History and Damage done.

The sporophores or fruiting organs are developed at the base of the Deodar stems and will also probably be found on the roots below the ground surface. They arise from cushions of mycelium which force their way to the surface of the stem or root at these points, where the sporophores first appear as small, rounded, chocolate-brown nodules. These increase in number and run together forming a brown incrustation broken by numerous ledges and tubercles. On the younger portion of the sporophore a series of imbricate bracket-like protrusions are developed. The lower surface of these brackets is white and contains numerous minute pores, on the walls of which the spores are developed, while the upper surface is rough, brown, and covered with tubercles and concentric ridges. It is probable that these spores are often carried in the ground on the fur of mice and other burrowing animals and are rubbed off on healthy roots. On germination they give rise to very delicate hyphæ which penetrate between the bark scales, force their way into the wood and give rise to characteristic white sheets and bands of mycelium, between and under the bark scales. The roots are not the only parts affected. Broad bands of the mycelium invade the collar, ascending the stem and forcing their way along the cambial layer, in feathery strands of snow-white tissue. These completely destroy the cambial layer. In addition to this the wood is directly attacked and destroyed by the minute hyphæ which bore their way from cell to cell by means of a cellulose-dissolving enzyme which they exude. The lignin in the cell-walls of the attacked wood is dissolved out first by the hyphæ and the middle lamella is destroyed, so that the wood elements fall apart. As a result of this action white areas of diseased wood arise which are very characteristic and which are usually elongated in the direction of the long axis of the stem. They consist of dissociated cells of practically pure cellulose, which, being themselves ultimately decomposed, leave small hollows in the wood. Before decomposition is completed the cell-walls show a fine striation and, later, large spiral cracks. Living cells in the wood paren-

chyma and medullary rays attacked by the hyphæ become filled with a brown substance, probably caused by the decomposition of the protoplasm. This discoloration is more noticeable in the roots than in the stems of the Deodar. A remarkable characteristic of this fungus is the possession of *rhizomorphs*. These are branched, cylindrical, or flattened, bodies composed of an outer, black and somewhat brittle, cortex, formed of interwoven tough brown hyphæ and of a central, tough, flexible, whitish portion composed of fine hyphal filaments. In general appearance these resemble the black petioles of some ferns and are not unlike the ordinary fine Deodar roots. They are, however, blacker, of a different consistency, and do not taper regularly towards the apex. They can be distinguished by splitting them longitudinally when the silky white medulla can be teased out with the fingers. These are organs of propagation possessing the power of apical growth. Springing from the mycelium in the roots of diseased trees, they travel below the surface of the ground and, penetrating below the cortex of any healthy Deodar roots which they may encounter, develop in them the ordinary mycelium, and thus spread the disease from tree to tree. Trees growing close together in the forest often have their roots in close contact and are frequently found grafted together. It is probable that infection often takes place by the mycelium thus growing directly from one root into another which is in contact with it. For illustrations, see *Plate XVII.*

Preventive Measures.

The only measures likely to be effective are the removal of attacked trees to prevent the formation of sporophores and the isolation of infected areas by trenches dug a few feet deep and sufficiently far from the centre of infection to include all diseased roots and rhizomorphs. It is doubtful if this could be done profitably on a large scale.

Armillaria mellea.

169. In its life-history and action on the plant attacked, *Armillaria mellea*, which has been briefly noted in *Part IV* above, has several points of resemblance with the fungus just described, see page 133. *Armillaria*, however, is particularly interesting as being one of those fungi which, although living at times in a purely parasitic manner, are also able to exist as saprophytes. This fungus may accordingly sometimes be found thriving on wood used in construction, *e.g.* in bridges, and also on dead roots and stumps, and at others as a virulent parasite attacking and killing living trees. From cases such as these we

conclude that no hard and fast line can be drawn between these classes of saprophytes and parasites, and there is every reason to believe that the one mode of life has led to the other. At the same time it must be remembered that a hypha, which is able to pierce the cell-walls of a plant's tissues, is not by any means necessarily able to kill the living protoplasm in the cells.

(3) *Trametes Pini* Fries. Species attacked.

170. In India this destructive fungus has been found on *Pinus excelsa* near Simla, and it is well known on various conifers in Europe.

Signs of the Disease.

The characteristic sporophores usually first indicate the presence of the fungus. These appear on the stem usually near the stump of a dead branch, and are hard, bracket-like, masses often triangular in section. The upper surface of the sporophore is rough, blackish-brown in colour and with concentric grooves, the fawn-coloured lower surface is covered with the minute pores in which the spores are developed. See *Plate XVIII* (*a*).

Life-History and Damage done.

In many respects the damage done by this pest resembles that described above in the case of *Fomes annosus*, but it is important to note that, whereas the latter fungus can attack sound roots, *Trametes Pini* can only attack a tree through an existing wound, and it is consequently termed a "wound parasite". The spores, alighting on a wound which is not covered with resin or other protective substance, on germination produce hyphæ which penetrate into the stem. The hyphæ bore through the cell-walls and extract the lignin in them so that practically pure cellulose is left behind. Characteristic white spots, which eventually become holes, then appear in the attacked wood, see *Plate XVIII* (*b*). The growth of the mycelium may also cause cup-shake, or ring-shake. The timber is thus rendered useless, and if the tree attacked cannot oppose the invading mycelium by a copious flow of resin the hyphæ may spread to the cortex and kill the tree. Wounds caused by breaking or cutting off old branches which contain heart-wood are favourite points of attack, for little or no turpentine exudes from the central portion of such wounds, into which in consequence the hyphæ readily penetrate. For the same reason such wounds also afford a convenient passage free of resin by means of which the mycelium can pass from the interior of the stem to the outside for the purpose of producing sporophores, the latter frequently appearing at such places. Sporophores are not as a rule produced until a luxuriant growth of mycelium has

established itself in the interior of the stem, and if one sporophore is removed another as a rule soon takes its place.

Preventive Measures.

Diseased trees must be removed as quickly as possible. Wounding and injuring living trees must be avoided, and cut surfaces should be covered with tar or other protective substance. So far as we can, we must help the cambium to cover over as quickly as possible all wounds which may arise.

(4) *Puccinia graminis* Pers. Species attacked.

171. It has been estimated that the annual financial loss in India, on account of the damage done to cereal crops by the fungoid diseases popularly known as Rusts, is probably not less than Rs. 4,00,00,000. The best known rust in India is *Puccinia graminis* which is very destructive to wheat, and which we may also take as a type of the great group of parasitic fungi to which the rusts belong, *viz.* the *Uredinaceae.*

Signs of the Disease.

The first sign of the disease consists in the appearance of orange-red streaks and patches on the green wheat leaves, culms and even on the ears, which in Northern India usually happens in January—February. These rust pustules swell and, bursting through the epidermal tissue of the wheat plant, scatter spores which look like reddish dust and are called *uredospores.*

Life-History and Damage done.

If the tissues of the wheat plant are examined with the microscope the mycelial threads of the fungus will be found ramifying in all directions between its cells. This mycelium derives its nourishment from the green cells of the wheat plant and consumes the food materials which should go to form the grain; consequently the yield of the latter is enormously reduced. After growing and spreading in the tissues of the wheat plant for two or three weeks the hyphæ turn towards the epidermis, and the orange, oval, one-celled uredospores are budded off from their tips; the gradual accumulation of these hyphal branches and the spores which they shed result in the swelling of the pustule and ultimate rupture of the epidermis with the scattering of the spores. If these spores fall into water they germinate and send out two or more germ filaments [see *Plate XIX* (*2*)], one of which outstrips the rest and either dies in the absence of a suitable host or, in the event of its having alighted on a wheat plant in a drop of rain or dew (which would often happen in a wheat field), finds its way into a stoma and rapidly gives rise to a new mycelium, which in due course produces a fresh crop of uredospores. The function of these spores is thus to spread the disease rapidly from plant to plant, wind aiding

their distribution. Now as the season progresses, the mycelium which, for some weeks, has only produced uredospores, now begins to form a totally different kind of spore, which are known as *teleutospores*. These, instead of being orange or reddish in colour, are dark purple-brown or black, and their formation can be recognized by the appearance of grey streaks and patches among the orange ones which spread and get darker in colour, until ultimately the black pustules entirely replace the rust-coloured ones which preceded them [see *Plate XIX* (*1*)]. These teleuto-spores are formed in the same manner as the uredospores and by the same mycelium, the latter in the beginning of the season producing only uredospores, then later a few teleutospores among the uredospores, and ultimately nothing but teleutospores. These spores which are formed by the fungus in the later stage of its life-history, besides being quite distinct in appearance from the uredospores, have a different function, they being virtually resting spores. Besides the difference in colour, each teleutospore instead of being one-celled is divided across the middle into two cells or chambers. They are more elongated and club-like in shape and have a thicker wall. They are also as a rule not shed so quickly as the uredospores but remain firmly attached to the wheat straw. They are generally incapable of germinating for some months after their formation. When they do germinate each cell sends out a short hypha which then becomes divided by cross partition walls into segments. From each segment a short lateral stalk (*sterigma*) is produced, the tip of which swells and then falls off—the minute, ovoid, spore-like bodies so formed being called *sporidia*. The short hyphal filament developed from the teleutospore is known as the *promycelium*. See *Plate XIX* (*3*).

Now in Europe it was found that these sporidia could only develop if placed on a new host-plant, a species of *Berberis*, *i.e.* an altogether distinct species from that on which the teleutospores were formed. Germinating then on the leaf of a suitable host-plant, these sporidia send out their germ tubes which directly pierce the leaf-tissue of the Berberis and develop a parasitic mycelium within it, the mycelium deriving its nourishment from the cells of the Berberis tissue. Although the Berberis plant is thus more or less injured, the damage done is usually not severe, and the great practical importance of this fungus depends on the injury done to the wheat plant, which results in an enormous decrease in the yield of grain. The presence of the mycelium in the Berberis induces swellings in the leaf tissue on which two different kinds of spores are produced.

The first to appear called *spermatia* arise in small cup-like receptacles on the upper surface of the leaf. They are very minute, and their function is at present unknown. On the under-surface of the leaf, larger, golden-yellow, cup-like receptacles arise, which are clearly visible to the naked eye and are often known by the popular term of "cluster-cups". These cups have fringed white margins and are filled with golden-yellow spores. They arise first beneath the epidermis as hollow balls, the membranous walls of which are formed by the fungal hyphæ and constitute what is known as the *peridium*. The base of these balls is formed by a number of short hyphæ with their ends directed towards the apex of the ball. From the ends of these hyphæ spores are abjointed in succession from the apex downwards, long chains of spores being thus produced. As the formation of spores proceeds, the ball swells and ultimately the epidermis of the leaf and the peridium covering are ruptured and the ball becomes a cup-shaped receptacle projecting from the leaf surface. As the spores escape from these receptacles and are distributed by the wind, fresh ones are developed from the hyphæ at the base to replace them. See *Plate XIX* (*4*), (*5*) and (*6*). This form of the fungus developed upon the Berberis was at first thought to belong to a distinct genus from that which included the form occurring on the wheat; it consequently received the name of *Aecidium Berberidis*, and it was long before the connection between the two was established. The cluster cups are called *aecidia* and the spores developed in them *aecidiospores*. These spores are very like the uredospores except that they are more golden-yellow in colour and are often somewhat polygonal in form, owing to the pressure which they have undergone. These spores, alighting on a damp wheat plant, send out germ tubes which, finding their way through the stomata, give rise to the mycelium in the plant tissue from which uredo- and teleutospores are ultimately produced as before. *Aecidium Berberidis* is found on *Berberis Lycium* near Simla and also probably occurs on other Indian species of *Berberis*.

We thus see that the complete life-history of this fungus comprises two distinct stages which may be called the Puccinial and Aecidial respectively, and these stages may be subdivided into four as follows:—

| | |
|---|---|
| Puccinial stage. | (1) The parasitic mycelium in the wheat plant developed from aecidiospores and giving rise to uredospores.<br>(2) The formation of teleutospores from the same mycelium. |

Aecidial stage.

(3) The germination of the teleutospores giving rise to a promycelium and sporidia. This is a non-parasitic stage.

(4) The germination of the sporidia to form a parasitic mycelium which ultimately produces æcidiospores.

In our typical example the puccinial and aecidial stages are passed on different host-plants; such a fungus is said to be *heteroecious*, and the host which nourishes the aecidial stage is in this case called an *intermediate* host. Other allied fungi pass both the puccinial and the aecidial stage on the same host-plant andare consequently called *autoecious*.

Now in the central areas of India *Puccinia graminis* is one of the commonest wheat rusts, and it has been found widely spread in places over 600 miles from any species of Berberis which in India are confined to the high hill ranges. In Europe also it has been found that wind-blown æcidiospores can ordinarily only infect plants within a radius of 25 yards from the bush on which they arise, and hence it is improbable that wind-blown æcidiospores could in such cases be responsible for the disease. This rust also is common in parts of Australia, *e.g.* in Victoria, where no Berberis grows wild and very few are cultivated. Again, if the æcidial stage on the Berberis is always necessary for the continued existence of the fungus, the complete destruction of all species of Berberis should suffice to eradicate the disease in the areas treated. This, however, has not been found to be the case. Finally *Aecidium Berberidis* is, in India, restricted to a portion of the Himalayan Range, and it is precisely in this area that *Puccinia graminis* is extremely rare on cereals. We are therefore driven to the conclusion that the fungus can, and often does, dispense with the æcidial stage and continues to exist on the wheat, year after year, in the puccinial stage. How this is managed is not yet clearly understood. It has been suggested that the uredospores may pass from the wheat to some wild perennial grass and that the fungus may thus continue to maintain itself on the latter in the puccinial stage until the season for the next wheat crop comes round again. In Europe this fungus has been found on 150 different species of grasses, including oats, wheat, barley and rye, these being known as *collateral hosts*. It has, however, been found that the form on wheat is exclusively limited to the wheat and cannot impart the disease to any other collateral host, with the sole exception of rye and barley, which in rare cases

may be infected. On the other hand, uredospores from other collateral hosts fail to infect the wheat, except in rare cases under very favourable conditions. It has in fact been clearly established that this wheat rust is a highly specialized form of the fungus which possesses very little capability of directly passing on to and infecting other nearly allied species of plants.* Another suggestion is that the uredospores may live in the soil during the period when wheat is out of the ground (between April and November) and be able to infect the young crop in December—January. Experiments, however, with allied fungi have shown that the uredospores soon lose their power of germination, especially when they are exposed to a high temperature, as they would be in the hot season in the plains of India.

These explanations therefore can hardly account for the persistence of the disease. Again it has been suggested that the sporidia may be able to give rise to a mycelium in the wheat plant capable of producing uredo- and teleuto-spores. This is improbable and there is no evidence to support it. The most recent researches on the subject indicate that the rust on wheat may be a truly hereditary disease. The protoplasm of the fungus is said to be able to exist in intimate union with the protoplasm of the wheat plant, and its presence then can only be detected with great difficulty. This state of things may continue for months, or even years, the disease germs passing on from generation to generation in the seed, and it is only under certain favourable conditions of moisture, heat, and of the state of the host-plant itself, that the fungus becomes distinctly visible in the form of a mycelium, which takes place just before the rust pustules begin to appear.

Preventive Measures.

The only practical measures at present available for combating this fungus consist in selecting the most rust-resistant varieties of wheat for continued cultivation and in endeavouring to produce new and improved varieties by inter-crossing.

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* Seeing that the various forms of this fungus, occurring on different collateral hosts, are each more or less confined to some special species of plant we cannot doubt that in some way they differ essentially from one another. At the same time, so far as visible microscopic characters are concerned, these forms cannot be distinguished and hence they are all grouped under the species *Puccinia graminis*. Here we appear to have an example of the power possessed by some plants of adapting themselves to changed conditions, and we see that, having become accustomed to one set of conditions, they do not readily adapt themselves to another, although in time a specialized form may arise which can do so.

*Aecidium montanum.*

172. The life-history of several other rust-fungi exhibit the two stages described above, *viz.* the Puccinial and Aecidial, but, as our selected example clearly shows, these two stages are not always necessary. Thus there are species of Puccinia of which no Aecidial form is known and *vice versâ.* As an example of an Aecidium of which no puccinial stage is known, we may take the "cluster-cups" so often seen on *Berberis Lycium, B. coriaria,* and *B. aristata,* in Jaunsar and near Mussoorie. This species has been named *Aecidium montanum.* The mycelium of this species is perennial, the hyphæ running in the cell walls and intercellular spaces of the stem and leaves and obtaining food by means of little finger-like haustoria pushed through the walls. Its presence in the tissues of the Berberis causes the formation of very characteristic witches' brooms. The affected shoots become dwarfed, bear malformed leaves and grow vertically upwards, the long, yellow, aecidial cups occurring in masses on the underside of the leaves and also scattered on the shoots and sometimes on the peduncles, from which the clouds of powdery orange aecidiospores are shed and disseminated by the wind. Sometimes more than half the bush may be affected in this way. A healthy bush on first infection shows large, reddish, or scarlet, patches on the upper surface and numbers of the long aecidial cups below. In this case there is no deformity beyond a puckering of the leaves, and it is uncertain whether first infection takes place by aecidiospores or by sporidia. If by the latter, the puccinial form bearing the teleutospores is still unknown. This species is distinguished from *A. Berberidis* by the witches' brooms, by the greater length of the aecidial cups, which may amount to 4 mm., and by the greater size of the patches seen on newly affected normal leaves, which ranges from $\frac{1}{4}$ to $\frac{3}{4}$ of an inch in diameter.

Parasitic Phanerogams.

173. The following may be taken as typical examples of parasitic phanerogams :—

(1) *Orobanche indica.*
(2) *Cuscuta reflexa.*
(3) *Loranthus longiflorus.*

(1) *Orobanche indica.*

174. The handsome spikes of pale purple, or blue, flowers of this plant are often seen in the mustard fields of Northern India, and the total absence of green leaves at once strikes us as peculiar.

This species being thus unable to manufacture for itself the carbonaceous organic food materials which it requires is obliged to obtain them ready-made from other plants. If the soil is carefully removed from the roots of an *Orobanche* plant these are found to be joined to, and in intimate connection with, the roots of the neighbouring mustard plants from which they take their necessary food materials.

175. This is the well-known leafless Dodder, masses of whose wire-like stems may often be seen enveloping trees and shrubs with a yellow, or greenish, mantle. Although the plant contains a little chlorophyll, this is quite insufficient for the manufacture of the food it requires. If we examine the twining stem we find that, where it comes in contact with the stem or twigs of the host, small wart-like protuberances are developed which pass into and are in intimate connection with the tissues of the host from which it derives its water and nourishment. These suckers, or haustoria, are able to force their way into the tissues of the host without difficulty, partly owing to the action of dissolving enzymes which their filaments excrete after the manner of fungal hyphæ. The seed of this species germinates on the ground, but the rootlet which is developed soon dies off, and if the filamentous stem fails to encounter a suitable host the seedling perishes. If allowed to develop undisturbed the Dodder may kill the plant attacked, and gaps in garden hedges caused by it may often be seen. (2) *Cuscuta reflexa.*

176. This very common plant may be taken as fairly typical of the numerous species of *Loranthus* and *Viscum* which occur in Indian forests. Their chief peculiarity consists in the fact that they possess a considerable supply of chlorophyll, many of them, like our example, being provided with well-developed green leaves. This plant appears to be chiefly distributed by birds who deposit the seeds on the branches and stems of trees where they germinate and grow. The young radicle, piercing through the cortex of the branch or stem attacked, penetrates to the young wood, in the tissues of which it spreads and develops. This plant obtains its supplies of water and mineral salts directly from the wood elements of its host and the portion of the branch or stem above the point of attachment of the parasite, being deprived of its water-supply, dies and we get stag-headed trees. The attacked branches become swollen and disfigured while the parasitic roots, being embedded in the wood, (3) *Loranthus longiflorus.*

render the latter more or less worthless for construction. It is probable that this plant transfers some of its carbonaceous food materials to its host, but it is not known whether it absorbs any organic food substances from the host in addition to the supplies of water and mineral salts. The chief practical method of combating this pest consists in cutting off and destroying the attacked branches.

*Santalum album.*

177. Among parasitic phanerogams which are furnished with an abundance of chlorophyll the well-known sandal tree (*Santalum album*) requires brief notice. It is now known that this tree is dependent to a very large extent on the roots of the plants near which it grows for its supplies of water and mineral salts, the Sandal roots developing numerous haustoria which penetrate the root tissues of the host-plants and draw from them the necessary supplies of food materials. No definite information is at present available as to the extent to which the host-plants are damaged by this parasitism, and it appears probable that they may benefit to some extent by a supply of carbonaceous food which has been manufactured in the green sandal leaves, in which case the partnership would be more or less a reciprocally-symbiotic one. Numerous costly attempts have been made to artificially propagate sandal in pure plantations which, owing to the absence of other trees and shrubs, were of course failures, and although this tree is of such great economic importance it is a remarkable fact that its parasitism was until quite recently regarded as uncertain. It is, therefore, not a matter for surprise that the artificial propagation of this tree was frequently a failure, or that the notorious " spike " disease from which it suffered had baffled all attempts at explanation and prevention. Until we know the principal conditions essential for the healthy development of our important species, it is obvious that we cannot expect to propagate them successfully or to discover the cause of, or remedy for, any disease which may attack them. Hence we must recognize the paramount importance of studying the life-histories of our forest plants and the relations which exist not only between them and their non-living environment but also between them and other living organisms.

Leaving parasites we now pass on to :—

### (c) *Symbionts.*

Lichens.

178. Perhaps the most typical example of symbiosis among plants is afforded by

the lichens. As has been seen above, a lichen consists of two distinct plants, *viz.* an alga and a fungus, see page 137. The fungus receives carbohydrates from the alga in return for which it protects the alga from drought and provides it with water and mineral salts.

179. Another well-known example is furnished by the bacteria which, as noted in *Part IV* above, see page 129, live in the tubercles often found on the roots of the Pea, Bean and allied plants belonging to the Natural Order *Leguminosae.* The best known of these bacteria is named *Bacillus radicicola* which, passing through the root hairs, gives rise to the peculiar tubercles in the root cortex of the infected plants. The bacteria are localized in these tubercles and do not spread to neighbouring tissues. While the bacteria live on the carbohydrates supplied by the host they, in their turn, are able to provide the host with valuable nitrogenous food materials, owing to the power possessed by them of fixing the free nitrogen of the air and of manufacturing from it a compound which can be utilized as food by higher plants. Owing to this remarkable symbiosis by means of which most leguminous plants can accumulate nitrogenous organic material in their tissues, a crop of such plants can actually enrich a soil poor in nitrates. Hence in agriculture it is a common practice to grow such plants and to plough in the crop as manure.* In a soil rich in nitrates, leguminous plants can obtain their nitrogenous food without the aid of these bacteria, and in such cases very few, if any, tubercles are formed. Bacteria and *Leguminosae.*

180. The majority of the higher plants cannot directly utilize as food the organic substances, such as the dead remains of plants, wood, leaves, etc., which compose the humus of the Forester. Hence such plants are found to grow normally when supplied solely with water and the necessary mineral salts. Many plants, however, such as pines, oaks, the hazel and others, can thrive on humus soils, and in the majority of such plants their roots are found to be living in symbiosis with the mycelia of fungi. The fungal hyphæ are sometimes found chiefly inside the cells of the root cortex, a few fila- Mycorhizas.

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*If leguminous plants could be grown continually on the same soil the supply of nitrogen in the latter might clearly be increased indefinitely, but unfortunately this is not at present possible. Experiments in Europe have shown that clover can only be successfully grown on the same soil about once in four years and sometimes even not so frequently. The reason for this is at present unknown.

ments here and there extending into the soil, and at other times they cover the roots externally with a felt-like mantle. Such mycelial growths are called *mycorhizas*. In Europe it has been found that if trees like the oak and pine are grown in sterile soil and are thus deprived of these mycorhizas their growth is retarded and sometimes entirely prevented. The precise nature of the symbiotic relation in this case is not yet known, but it is probable that the host supplies the fungus with carbohydrates, while the fungus helps the host to obtain water, mineral salts (probably phosphates and potassium chiefly) and simple nitrogenous compounds.

Distant Symbiosis between Green and Non-green Plants.

181. The above are all instances of close symbiosis, *i.e.* in which two organisms live in intimate connection with each other. As an example of distant symbiosis we may take that existing between green and non-green plants.

We have had frequent occasion to mention above the decomposing action of many bacteria and fungi which give rise to various processes popularly called rotting, putrefaction, fermentation, nitrification, etc., such organisms being able to feed on complex organic materials and to break them down into simpler substances on which the higher green plants feed. By the activity of such organisms, for instance, the carbon dioxide required by green plants is being continually returned to the air, while nitrogenous organic substances such as albuminoids, amides, and others are also broken down and nitrates produced which are the chief source of nitrogenous food for higher plants. Many of these decomposing processes are accompanied by a liberation of energy in the form of heat, and we know that the heat may be so great, in a stack of rotting hay, for instance, that spontaneous combustion is produced.

Decay of Wood.

182. Before leaving this subject of decay a few words will be added on the decay of timber. In the first place care must be taken to distinguish between the terms dead and decayed. Plant tissues become dead when their elements lose their living protoplasmic contents, they do not become decayed until they have undergone a further process in which they become disintegrated and their structure is destroyed. A piece of sound, Teak heart-wood, which is really dead tissue, and which is known to be the best and most durable wood for construction, compared with a fragment from a hollow tree which

can be crumbled in the fingers will illustrate the difference. For the decay and destruction of structural timber fungi are mainly responsible, their hyphæ excreting enzymes which destroy the wood tissue, as has been made clear in the examples of *Fomes* and *Trametes*, and it is therefore important to remember that, as a general rule, the conditions most favourable for the development of such fungi are:—

(1) A supply of organic food materials such as carbohydrates and proteid substances which are commonly found in sapwood.
(2) Warmth.
(3) A liberal supply of moisture and absence of free ventilation.
(4) A supply of oxygen.

Thus sapwood, especially if kept damp, quickly decays, and in the case of posts driven into the ground we frequently see that decay spreads most rapidly in that portion of the post situated in the upper, well-ærated, layers of soil.

Seeing also how fungal hyphæ may spread from a decayed piece of wood to a sound piece in contact with it, and how easily the minute spores are distributed, it is clear that the greatest care must be taken if we wish to preserve sound wood from infection.

## Section III.—Influences of the Soil on plant development.

**Presence of Necessary Salts in a suitable Condition and in suitable Quantities.**

183. For the healthy development of plants the soil must contain a sufficient supply of all the essential mineral salts. These may, for instance, be so diminished by the competing roots of neighbouring plants as to cause disease and death, the absence of any one of them making growth impossible. Further these salts must exist in such a state of combination as to enable the plant to make use of them as food materials, and they must not be present in excess. The best nutrient solution for most phanerogams, for example, should not contain more than 0·5 per cent. of salts.

**Presence of Poisonous Substances.**

184. Any substance which may cause disease or death in plants may be broadly classed as a Poison. If the solution of salts in the soil becomes concentrated beyond a certain limit, rarely exceeding five per cent, owing to the osmotic processes being interfered with, the roots of plants

are no longer able to obtain their necessary supplies of water from the soil and are thus in danger of desiccation. At the same time plants vary in this respect and there are many (usually known as *halophytes*) which can thrive on saline soil and are able to recover the necessary water from concentrated solutions of salts. There are also many substances which have a more directly poisonous effect on plants and such are as a rule the salts of the heavy metals, *e.g.* sulphate of zinc and others. Free acids and alkalies are also very poisonous even when dilute. Carbon dioxide is continually excreted by the roots of plants and, in water-logged localities, the accumulation of this gas may have a poisonous effect. The escape of coal-gas from underground pipes, or chemical solutions from factories, such as dye-works, may also kill and injure plants. Again many essential mineral salts, and others which, though not essential, are often found to be taken up by plants, may have a poisonous effect if present in large quantities. A trace of iron is thus essential for plants, but a very dilute solution of an iron salt may be poisonous, the quantity of the salt present being above the optimum. Calcium appears to be injurious in some cases, while as regards common salt it is not clear if its injurious effect is merely due to its osmotic properties or to a more direct poisonous action. In the majority of cases the exact way in which the poison acts is not known, but sometimes at all events the poisonous substance appears to enter into chemical combination with some constituents of the protoplasm, much as in the case of animals carbon monoxide combines with hæmoglobin. Humus by its absorbing action has a most beneficial effect in protecting plants from poisons. Poisonous metallic salts may thus be strongly held by the humus and only allowed to pass into the soil in very dilute, harmless solutions. The principal product which is excreted in large quantities by the roots of higher plants is carbon dioxide, and this being a gas rarely accumulates sufficiently to be injurious.

Many plants are also able to accumulate considerable quantities of poisonous substances without injury, by depositing them in dead tissues, or in living ones in such a way that they cannot penetrate the living protoplasm.

**Presence of Necessary Water and Oxygen.**

185. Unless the root-hairs are able to obtain a sufficient supply of water and oxygen in the soil they cannot perform their functions properly, and a good soil, besides being sufficiently moist, must, therefore, be open and well ærated. The amount of available water in a forest

soil may be decreased by a diminished rainfall and by the more or less complete failure of the monsoon, by draining, by the removal of litter, or by interrupting the leaf canopy, and this may cause trees to become stag-headed. The same result may be caused by underplanting trees with a species which absorbs large quantities of moisture from the soil. In an ordinary well-drained soil oxygen is always present as gas in the interspaces and also dissolved in the water. If this oxygen is removed the root-hairs are killed and the roots rot, the trees becoming stag-headed. This may be caused by water being allowed to stagnate around the roots as happens in swampy ground, and it commonly occurs also in dense soils and in soils with an impermeable substratum. The available oxygen in such cases is gradually exhausted, that utilized by the roots being not replaced sufficiently quickly by the admission of fresh air. The same result may be caused by other factors which interfere with the free æration of the soil, such as heavy grazing which hardens and increases the density of the soil. The roots of plants grown in glazed pots are unable to obtain a sufficient supply of oxygen and often rot in consequence. Similarly trees growing in towns are often unhealthy, owing to the buildings and close pavements preventing sufficient water and air entering the soil.

The free æration of the soil is also important for another reason. We have seen above that organic substances, such as humus, cannot be directly used by the higher plants as food, although such substances always contain a certain quantity of the elements, such as phosphorus, potassium, nitrogen, etc., which are essential for the existence of such plants. Without the aid therefore of fungi and bacteria which break down this organic material and liberate these elements in a suitable condition, they could not be utilized by the higher plants and consequently humus would accumulate in our forests and the soil would gradually become poorer in the essential food materials, until eventually no trees could grow in it. Now a sufficient supply of oxygen is absolutely necessary for the existence of a large proportion of these useful fungi and bacteria, and they are in consequence found in the upper layers of the soil,* where, moreover, their presence is most

* Experiments have shown that when impure sewage water containing large numbers of bacteria is passed through sandy soil most of the bacteria are retained in the superficial well-ærated layers of soil, on which fact the system of filtering water through sandy soil is chiefly based.

needed, seeing that this is where organic débris chiefly accumulates. Thus from this point of view alone we see how enormously important is the proper æration of the soil, as also is, of course, the quantity of moisture in the soil, and its temperature, and indeed all factors which may favour or retard the development of these useful living organisms.*

Accumulation of Starch in the Leaves indicates Root trouble.

186. Now if for any of the above reasons a plant is unable to obtain its necessary supplies of water and mineral salts from the soil, the carbohydrates manufactured in the leaves cannot be converted into plastic materials and thus be conducted away to the growing tissues which require them, but, owing to the deficiency of water, have to be put aside as starch, and hence an accumulation of starch grains in the leaves is often an indication that we must look to the roots for the cause of a disease.

## Section IV.—Influences of the Atmosphere on plant development.

Extremes of Temperature.

187. For every external factor which affects the growth and development of a plant, such as temperature, light, etc., there is, as has already been noted in *Part III*, a certain degree of intensity called the *optimum* which is most favourable to the plant, see page 86. Any considerable departure from this limit may cause disease and if carried far enough death. Thus, as regards temperature, the death of plants may be caused either by excessive heat or cold. The power of a plant to withstand extremes of temperature depends chiefly on the species of plant and its stage of development. Most flowering plants are killed by a long exposure to a temperature of 45° C., while some bacteria grow well at a temperature of 70° C. Potato plants may be killed in one night by a temperature of—4° C, while some bacteria can withstand a temperature of—200° C. Khair (*Acacia Catechu*) and Ber (*Zizyphus Jujuba*) are frost-resistant, while Aonla (*Phyllanthus Emblica*) is frost-tender in the climates where

* In connection with this breaking down of organic material by fungi and bacteria it is interesting to note that this process may not only result in the production of very valuable plant food materials, but may also convert evil smelling organic substances, such as are contained in sewage, into simpler substances which are absolutely free from odour and inoffensive, a fact which is utilized in the disposal of sewage in towns, the sewage being collected in tanks where it is exposed to the action of various fungi and bacteria.

they usually grow. Again, as regards the stage of development, we know that many trees which are easily killed by extremes of temperature as seedlings are resistant when older, and that, for example, flowers and young leaves may be readily injured while resting buds are very resistant. The quantity of moisture also present in a plant materially affects its power of withstanding extremes of temperature. Many mosses and lichens are easily killed when moist, but are extremely resistant when dry. The more water contained in plant tissues the more likely are they to be injured by frost.

Effects of Excessive Heat.

188. Excessive heat most commonly injures plants in one of the following ways:—

(1) By causing the drying up and death of leaves, twigs, branches, or even entire plants and trees, owing to the abstraction of water from the plants themselves and from the soil in which they grow. The roots are thus unable to obtain sufficient moisture from the soil to make good the losses occasioned by increased transpiration. This form of injury is most destructive in India in years when the more or less complete failure of the monsoon has lowered the level of all springs and considerably reduced the amount of moisture ordinarily available in the soil.

(2) By splitting the stems of trees. Intense heat, drying up the outer tissues of a stem and thus causing them to shrink, gives rise to splits in the wood very similar to frost cracks. Thin-barked species, such as *Phyllanthus Emblica*, may thus be found split to the centre, especially in years of drought.

(3) By directly scorching and killing the cambium and other living tissues, thus causing cancerous patches on the stems, or the death of entire trees. This is often caused by the sun's rays impinging on thin-barked stems, especially those which have grown up in shade and then become exposed by the felling of the surrounding growth, as happens in the case of standards in a coppice.

Effects of Excessive Cold.

189. Excessive cold usually results in one of the following modes of injury:—

(1) The direct freezing and killing of parts of plants, such as the leaves, twigs, etc., and even of entire plants

and trees. The injury or death is in this case caused by some change in the protoplasm brought about by the low temperature in a way which is not yet understood, and which varies for different species. On freezing, ice usually forms in the intercellular spaces, water being withdrawn from the cells. This withdrawal of water and drying of the cell contents appears to be the cause of death in some cases. As a rule the rapidity or otherwise of the freezing or thawing has no specially injurious effect, the injury being due to the low temperature, although we can generally only see if a plant is dead or alive after thawing. (This action must be distinguished from that of indirect desiccation, (2) below, in which a sudden rise of the air temperature may be very injurious, by increasing transpiration from the leaves while the roots are still inactive in frozen soil.) The temperature of plants may be very considerably reduced by radiation which may result in the temperature of the plant being as much as 8° C. below that of the air. Radiation is reduced by fogs, clouds, dust, or smoke, and the kindling of smoky fires is often efficacious in preventing frost damage, as also are artificial coverings of various sorts. The temperature of the leaves, twigs, and more delicate ærial portions of plants chiefly depends on the temperature of the surrounding air, and hence the damage done by frost depends to a great extent on the locality. The absence of air currents is one of the most important factors which affect the air temperature and hence low-lying enclosed situations where there is little or no circulation of air are particularly liable to frost damage. Such are the grassy blanks so frequently seen in Sal (*Shorea robusta*) forests, in which the circulation of air is prevented by the dense wall of high Sal forest surrounding them on all sides and where the cold air collects and stagnates. In such places all Sal shoots are killed down year after year by frost, whereas small patches of Sal forest may often be seen in the same locality untouched by frost, owing to the open cultivated ground on all sides of it promoting the free circulation of air currents. In these frosty localities the cold air collects like

water in a lake, and the height to which it rises is usually clearly marked by a definite line above which growth is uninjured. This was well seen in the Sal forests of the Dehra Dun during the severe winter of 1904-05, a definite line being clearly visible, running along the flanks of the Siwaliks, below which the leaves on every tree were brown and dead, those above the line being green and uninjured. The presence of large quantities of water in the soil may considerably reduce the air temperature, as may also a heavy growth of grass which reduces the temperature by radiating heat, transpiring moisture, interfering with the free circulation of air, and with the access of heat to the soil. Observations have shown that the temperature on an area covered with grass may be 16° F. lower than that of a similar area with no vegetation. The effect of frost depends of course largely on the condition of the plant itself. Consequently two trees of the same species may be very differently affected in different localities. One growing in a damp warm valley may be killed, while another, in a more exposed situation at a higher elevation, may escape injury; the former owing its susceptibility chiefly to the longer period of its vegetative activity, the larger quantity of water in its tissues and to the latter being less completely lignified or otherwise matured.

(2) The indirect drying up and killing of plants or parts of them, the injury being caused in precisely the same manner as in the case of drought. When the soil temperature falls below a certain point the root hairs are no longer able to absorb the necessary supplies of water. While the roots are thus inactive, the leaves may be actively transpiring moisture under the influence of bright sun-light and dry air-currents. The leaves and branches may thus become completely dried up and killed. Trees which retain their leaves in winter are particularly liable to this form of damage and mahua (*Bassia latifolia*) and achar (*Buchanania latifolia*) may frequently be seen injured in this way. This mode of injury may often be recognised by the leaves commencing to die back from the tip, the tissues at the base of the

leaf-blade and especially near the midrib being often uninjured and green, while the rest of the leaf is shrivelled and brown, *i.e.* just those portions escape injury which can first intercept the water-supply on its entrance into the leaf and which only allow that quantity of water to pass on to the more distant cells which is in excess of their own needs. See *Plate XX*. The damage can often be well seen in a nursery after a frosty night, no injury to the leaves being usually noticeable until the plants have been exposed to the bright sunlight for some hours. It is obviously important that trees growing at high altitudes, where the leaves are often exposed to the bright sunlight when the roots are in soil still frozen, should be able to prevent transpiration as far as possible. We thus find that the high-level *Rhododendron campanulatum* and *Quercus semecarpifolia* have the undersurface of their leaves covered with dense tomentum. With regard to this form of injury it must be pointed out that roots situated in the superficial layers of soil are more subject to the effects of sudden changes in temperature, while those in the deeper layers of soil are chiefly affected by prolonged cold temperature. Thus in some cases we find seedlings suffer more than older plants, while in other cases the reverse happens. In the latter case the superficial roots, under the influence of a few hours hot sunshine, having been sufficiently warmed to become active, whereas the deeper roots are still in frozen soil. An artificial covering of straw, dead leaves, etc., on the soil over the roots of a plant may often prevent injury by frost, by moderating the temperature of the surface soil, and it is probable that the beneficial action of watering plants is often due to the temperature of the roots being raised sufficiently to become active thereby.

(3) The splitting of stems of trees. When the temperature is sufficiently low ice is always formed in plants, usually in the intercellular spaces, but in wood, where intercellular spaces are usually absent, in the lumina of the wood elements. As these spaces contain considerable quantities of air besides water, the water finds ample space for

expansion on being converted into ice. During the formation of ice, water is abstracted from the cell walls, and this results in the drying and shrinkage of the wood, just as happens when cut timber is dried in the air. During severe cold, especially if the temperature falls very rapidly, the outer wood layers shrink more rapidly than the inner warmer layers, and longitudinal cracks and fissures are caused in the stem. Such cracks may become occluded in the usual way, but subsequent frost frequently re-opens the wounds, and if this is repeated several times prominent ridges, or frost-ribs, result.

(4) The formation of cankers. Frost cankers are usually found at the base of a young branch which has been killed by frost down to the main stem. The callus forming at the base of the dead shoot is again killed by subsequent frosts, and with recurring frosts the cancerous area spreads. The growth of the callus is also interfered with by the pressure of the dead tissues under which it forms, and such diseased areas usually heal slowly, if at all, and afford a favourable point of attack for wound fungi. Cankers due to frost may be distinguished from those due to fungi as they only increase in size in frosty years.

(5) The uprooting of seedlings. When the soil freezes, the expansion which the water in its interstices undergoes, on being converted into ice, raises the surface of the soil and pushes up the roots above their original position. When the ice melts with the thaw the particles of soil fall away from the roots which become exposed and the plant falls over and dies.

(6) The mechanical bending and breaking of stems or branches, owing to the accumulation of snow or ice upon them. On hill sides the pressure of snow against the upper side of young stems often causes the latter to curve outwards at the base, and this curve, being retained as the plant grows older, is often visible in mature stems. This bending over of young stems often also ruptures the tissues on the uphill side and causes wounds which may give access to injurious fungi.

(7) The more or less complete destruction of flowers, leaves, twigs, and young stems, by hail. The damage done depends largely on the state of development of the plant. While mature leaves may only be penetrated by the hail-stones, giving rise to so-called "shot-holes," the injury being more or less local, tender young leaves may be torn into shreds and the tree completely defoliated. Such complete defoliation results in the loss of valuable food materials contained in the young leaves, while the tissues have to be depleted of their food reserves for the formation of fresh foliage, this reduction in the available food supply resulting in loss of increment and diminished production of flowers and seed.

Effects of Light.

190. All plants may be killed by sufficiently strong light, and the fact that disease-producing bacteria may be killed by a sufficiently long exposure to sunlight is obviously of great practical importance. In green plants the chlorophyll corpuscles are usually more subject to injury than the rest of the protoplasm. If the light is too intense these corpuscles lose their power of assimilation and may become permanently bleached. The necessity of protecting the chlorophyll corpuscles from intense light is indicated by the presence of colouring matters such as anthocyanin, to which the red or purple colour of many young leaves is due, and which acts as a protective screen to the chlorophyll, by the general absence of chlorophyll in the epidermis, and by the fact that the chlorophyll corpuscles when exposed to strong light arrange themselves in such a way in the cells as to be least exposed to its action.

On the other hand, deficiency of light may be no less injurious. In the absence of light, green chlorophyll is as a rule not formed and, the manufacture of food materials in the leaves being impossible, the death of the plant by starvation ensues. We know, for instance, how easily so-called "light-demanding" species may be killed by shade. Insufficient light causes the diseased condition known as *etiolation*, which is characterised by the development of abnormally long and thin internodes and small, or very thin, yellowish leaves, with unusually watery tissues. The thickness and rigidity of the cell walls is also diminished, and the laying of cereals is due to the shading of the lower portion of the haulms which thus become too weak to support the weight of the plants. Unless the etiolated

condition has gone too far the plants may recover with the access of sufficient light, but, owing to their abnormally thin and watery tissues, they are particularly liable to be killed or damaged by frost, fungi, and other injurious influences.

**Effect of Excessive Moisture.** 191. Somewhat similar to etiolation is the condition produced by an excess of moisture in a plant. This is chiefly due to transpiration not being sufficiently active to deal with the quantity of water pumped into the plant by the roots. The tissues become over-saturated with water, food materials are excessively diluted and can only be transported in sufficient quantity very slowly from one part of the plant to another, in consequence of which, as in the case of etiolation, growth in length is considerable, but the watery tissues are not properly matured and are very liable to be damaged by fungi, insects, frost, etc. This condition is, of course, distinguished from etiolation by the fact that green chlorophyll is present in the leaves and that the disease occurs in plants which have access to light. Plants with an abundance of water available for their roots, which are growing in a saturated atmosphere, are liable to suffer from the condition here described.

**Effect of Winds.** 192. Winds, besides uprooting trees, breaking their stems and branches and causing the development of stunted and misshapen crowns usually bending away from the prevailing wind direction, impoverish the soil by dispersing dead leaves and débris, thus preventing the accumulation of humus and also diminish the available supply of moisture in the soil. Winds may be also exceedingly destructive to plants by increasing transpiration. Dry winds in cold frosty weather are particularly injurious, the roots in the cold soil being then unable to replace the water removed by transpiration, the plants being more or less injured, if not killed, by desiccation.

Observations have shown that the velocity of a wind which, at a height of $1\frac{1}{3}$ feet above the ground, was only 22·2 miles per hour, may be as great as 42·7 miles per hour, at a height of 51 feet above the ground. Consequently tall plants and especially tree-growth suffer much more from winds than shrubby or herbaceous growth. It should be noted that in the case of the Banana the tearing of the large leaves by the wind is a normal condition leading to advantageous æration of the leaves. Winds are also advantageous in the way of distributing pollen and seeds and aiding the distribution of plants.

Presence of Poisonous Substances.

193. The presence of poisonous substances in the air may cause disaster to plants just as may their presence in the soil. More than 4 per cent. of carbon dioxide in the air is injurious to many plants. Sulphur dioxide and fumes of hydrochloric acid are especially harmful, to which fact is to be attributed the injurious effect of an excessive amount of coal smoke, such as occurs in many towns, and of the fumes from iron-smelting furnaces, alkali and other chemical works. The foliage of plants thus injured usually turns yellow, and the plants become sickly and may eventually die. Trees usually suffer more than herbaceous growth and forests have been injured at a distance of 4½ miles from the place of origin of the poisonous fumes. The Plane (*Platanus*) is able to withstand the injurious effect of coal smoke and grows well in smoky cities, as do also as a rule maples, horse-chestnut and elms.

Effect of Lightning.

194. The action of lightning in causing the death or disease of plants is not clearly understood. In some cases a tree struck by lightning remains practically uninjured; a narrow strip of the cortical tissues is separated from the wood and the wound is soon occluded. In other cases, where the external signs of injury are similar, the entire tree may die. Stems of trees in some cases may be completely barked by lightning, in other cases they may be shattered into fragments and occasionally set on fire. The injurious effects may be confined to a single tree, or the lightning, passing from the stem originally struck to others near it, may damage a large group of trees. In the latter case the extensive damage appears to be often due to the lightning passing from root to root in the ground owing to the bad conducting nature of the soil. In such a case the injury spreads from a certain point in a centrifugal direction. Trees injured by lightning may sometimes remain alive for 4 or 5 years and then die.

## Section V.—Effect of Fire on plant-development.

Effect of Fire.

195. The injurious action of fires consists in destroying leaves, flowers, seeds, twigs, branches, seedlings and young plants, and in scorching, and more or less extensively injuring, the roots, cortex and cambium of older trees.

Moreover, the soil may be injuriously affected owing to the destruction of humus and to a decrease in the amount of available moisture. Fires may thus be responsible for wounds and

a diminished vitality, which render trees more liable to injury by fungi and insects, for loss of increment and for interference with reproduction. It has been noted above that different species vary in their power of resisting excessive heat, and while some plants are very sensitive to damage from fires others are less so. The effect of the fire on any particular species of plant depends mainly on the intensity of heat produced by the fire and on the state of development of the plant itself. A fire which may be beneficial shortly after the fall of the seed, by hastening germination, would be very destructive after germination has actually commenced. Seedlings of deciduous species which have their ærial parts destroyed by fire in the resting season may be very little damaged, while others burnt in the vegetative season may be seriously injured. The seeds of some species also are readily destroyed by fire, while those of others are protected from injury by hard or corky coverings, etc., and in the case of some species the germination of the seed appears to be aided rather than hindered by fire.

Necessity of Studying the Indirectly Beneficial or Injurious Effect of each Factor.

196. Finally, it must never be forgotten that a factor, in addition to any *direct* beneficial or injurious action which it has on the development of any particular plant, may also exercise a by-no-means less important *indirect* beneficial or injurious action, by affecting the development of correlated organisms. Thus winds may be directly beneficial in aiding fertilisation and the distribution of seeds of a certain species, while they are indirectly injurious by performing the same services for an injurious plant competitor, or by distributing the spores of an injurious parasitic fungus. Again fires may be indirectly injurious by damaging symbionts, such as useful soil bacteria or fungi, and indirectly beneficial by destroying, or retarding the development of, injurious plant competitors or parasites.

# PART VI.—GEOGRAPHY.

## CHAPTER I.—FACTORS INFLUENCING THE DISTRIBUTION OF PLANTS.

Factors affecting Distribution.

197. The principal factors affecting the distribution of plants will first be shortly considered under the following heads :—

(1) Water.
(2) Soil.
(3) Temperature.
(4) Light.
(5) Air.
(6) Existence of other Plants.
(7) Existence of Animals.
(8) Fire.
(9) Action of Man.

(1) WATER. Available Water depends chiefly on the Rainfall.

198. The water available for plants depends chiefly on the rainfall. In deserts, where the amount of moisture available for plants is exceedingly small, owing to the scanty rainfall, very few plants are able to survive and no forests exist. In India " really thriving forests are only found where the rainfall exceeds 40″, and rich luxuriant vegetation is limited to those belts which have a much higher rainfall. " * Owing to the low temperature prevailing at high elevations, mountains tend to condense aqueous vapour and thus receive more rain than the adjoining lowlands. The greatest rainfall, however, usually occurs at a comparatively low elevation and at higher altitudes, instead of periodic heavy falls of rain frequent mists and light rain occur, the rarefied air having a very small capacity for aqueous vapour. This accounts for the luxuriant growth of mosses and lichens often found covering the stems and branches of trees at high elevations. The outer ridges of a range of hills, also, which first intercept the currents of moisture-laden air, receive more rain than the inner hills, and thus Deoban, for instance, on the outer ridge in the North-West Himalayas, receives a greater rainfall than either Mundali or Kathian, while, at the same time, Kalsi, at the foot of the outer hills (elevation 1820′), receives a greater rainfall

* *On the Distribution of Forests in India* by Dietrich Brandis, p. 6.

than Deoban at the top of the outer ridge (elevation 9300′). The amount of moisture in the soil may be largely due to percolation from rivers, canals, or lakes, to which fact is largely due the characteristic vegetation of river-banks and of areas near large sheets of water.

Also on Percolation.

An important Indian tree which requires a very heavy rainfall is *Ficus elastica*, the Caoutchouc tree, and another tree which is usually confined to areas near rivers or to swampy ground is *Lagerstroemia Flos-Reginae*, one of the most important timber trees of Assam and Burma. On the other hand, *Prosopis spicigera* is a tree of some importance which can thrive in districts with a very small rainfall.

Action of Water in Distributing Seeds.

Under this head, also, must be considered the importance of water as an agent for distributing seeds. The sea is a great obstacle to the distribution of land plants. The fruit of the Cocoa Nut tree is provided with buoyant tissue which enables it to float, and its seeds are able to germinate after prolonged immersion in sea water. Many other plants have similar contrivances; their seeds are often distributed great distances by marine currents, and they are thus able to establish themselves on distant shores.

Water is largely responsible for the distribution of the spores of fungi, while rivers and streams play an important part in distributing the seeds of many plants. The seed of Sissoo (*Dalbergia Sissoo*), for instance, is chiefly distributed by water, and that of Khair (*Acacia Catechu*) frequently so.

Injurious Denuding Action of Water.

Finally must be noted the denuding action of water which, by washing away the soil, exposes the roots of plants, thus injuring the roots more or less, even if the plants are not actually up-rooted. The shrub *Rhabdia lycioides*, common in river-beds, with its creeping, rooting branches, is well adapted to withstand the action of torrential streams.

(2) Soil. Depth of Soil.

199. On bare rocks an insignificant vegetation, consisting chiefly of lichens, alone can exist, and on very shallow soil, capable of supporting a good growth of grasses, the majority of forest trees cannot thrive, hence the depth of the soil is of primary importance.

Supply of Mineral Salts.

It has been noted in *Part V* above that, for healthy plant development, the essential mineral salts must be present in the soil, and these must exist in a suitably dilute solution, see page 205. As the solution of salts in the soil becomes concentrated beyond a certain limit, plants experience increasing difficulty in obtaining their necessary supply of water from the soil. Many substances, also, exercise a directly poisonous effect on plants

and calcium and salts of iron often appear to be injurious in this way. Plants, however, vary greatly in their power of withstanding such injurious influences, and while some plants can thrive on a saline, or calcareous soil, others cannot exist there, a fact which is largely responsible for the characteristic vegetation of such soils. Among important Indian trees, *Butea frondosa* is remarkable for being able to grow on soil containing large quantities of salt.

Supply of Oxygen.

A supply of oxygen being essential for the healthy action of the roots of plants, the water in the soil must be well ærated and hence not stagnant. Many of our Indian trees are exceedingly sensitive in this respect and cannot exist unless the subsoil is well drained. The Deodar, *Pinus longifolia*, Sal, and many others, all require well-drained soil. On the other hand, many species can thrive in water-logged localities, *e.g.* *Butea frondosa*, *Terminalia Arjuna* and others.

Supply of Moisture.

The physical and chemical properties of the soil itself, and of the subsoil, influence the amount of available moisture to a considerable extent. Finely divided soils, such as clays, have the greatest power of absorbing water, and also, being very impermeable, of retaining it. Sand on the other hand, being very permeable, can retain very little water. Calcareous soils again have very little power of absorbing water, while those with an admixture of humus are capable of absorbing and holding large quantities of water. Among Indian trees which thrive best on clayey soils the well-known Sain, or Saj (*Terminalia tomentosa*), may be mentioned. Among trees often found on calcareous soils are Khair (*Acacia Catechu*) and Satin Wood (*Chloroxylon Swietenia*), but the fact that both these trees are commonly also found on non-calcareous sand, and on other soils in dry forests, indicates that the important factor in this case is the small amount of moisture in the soil and not the presence of a particular chemical constituent.

Characteristics of Laterite and Regur.

Two very characteristic and widely distributed types of Indian soils require brief mention here, *viz.* (1) *Laterite* and (2) *Regur*, generally known as Black, or Cotton, Soil. The first is remarkable for its very low capacity for holding water and for containing a large percentage of iron. The Eng, or In (*Dipterocarpus tuberculatus*), a valuable timber tree of Burma, is almost exclusively found on laterite. Many other species, often found on laterite, occur just as frequently also on other dry soils. Regur is generally found in the neighbourhood of trap rocks and consists largely of clay with a considerable admixture of organic

substances. It is characterized by its great adhesiveness when wet and by an extraordinary power of expansion and contraction under the influence of moisture and heat respectively. In the dry season it is traversed by great fissures, often many feet in depth. As a rule it is very fertile, especially for herbaceous plants and field crops, one of its names being due to its suitability for the cultivation of cotton. The Babul (*Acacia arabica*) is frequently found on this class of soil, as also is *Butea frondosa.*

Aspect, Slope and Underlying Strata.

Aspect, slope and the character of the underlying strata also obviously affect the loss of water from the soil through evaporation and drainage.

Effect of Vegetation.

Finally, there is the important factor of the presence, or absence, of vegetation on the soil. A covering of forest vegetation protects the soil from insolation and the effect of winds and thus diminishes evaporation; it leads to the formation of humus which absorbs and retains water well; the force of rain is broken by the leaves, twigs, and branches, from which it falls gently, and percolates into the soil, whereas on an area bare of vegetation much of the rain water runs off and is lost, especially on steep slopes. It must also not be forgotten that the rain water contains appreciable quantities of useful nitrogenous compounds and of mineral salts which are essential plant food-materials, so that, by intercepting the rain water alone, humus may considerably increase the fertility of a soil.

Soil the Principal Factor Determining the Distribution of Sal.

The character of the soil appears to be the principal factor determining the distribution of the Sal tree, this species requiring a loose well-drained soil, containing a considerable proportion of humus. It cannot thrive on the heavy soil which usually overlies trap rocks and, in Central India, the extension of Sal westwards is abruptly checked by these rocks, Teak forest commencing where the Sal forest ends.

(3) TEMPERATURE. Zones of Vegetation due to Temperature.

200. The effect of temperature on the distribution of plants has been recognised from very early days, and it was found that, if the surface of the globe was divided into zones of the same mean annual temperature, each of these zones was characterized by possessing particular species of plants, which did not thrive far beyond the limits of their particular zone. These zones are given in consecutive order below, that with the highest mean temperature first, and that with the lowest last.

I. Tropical Zone.—This is sometimes sub-divided into the Equatorial, Tropical and Sub-Tropical Zones.

II. Temperate Zone.—This is also usually sub-divided into the Warm Temperate and Cold Temperate Zones.

III. Arctic Zone.—This is sometimes divided into the Sub-Arctic, Arctic and Polar Zones.

The Zones in the northern hemisphere are usually termed *Boreal* and those in the southern hemisphere *Austral.*

The *Tropical Zone* is characterized by possessing Palms, Bamboos, Bananas, Tree Ferns, Cycads and Screw Pines (*Pandanus*), while the most important forest trees in this Zone, in India, belong to such natural orders as *Leguminosae, Dipterocarpaceae, Combretaceae, Urticaceae, Meliaceae, Verbenaceae, Guttiferae* and others.

In the *Temperate Zone* the most important forest trees belong to the *Coniferae* and *Cupuliferae,* the latter including the Oak, Beech, Chestnut, Hazel, Hornbeam, Birch, and Alder. Other characteristic trees are the Poplar, Willow, Elm, Walnut, Maples, and Holly, while among shrubs, *Berberis, Rhamnus,* and *Euonymus,* are common. One of the most typical natural orders is perhaps that of the *Rosaceae.*

The *Arctic Zone.* The species found in the cold temperate zone also extend into the arctic zone, but, in the latter, there are fewer species, and the vegetation is especially characterized by being stunted. The limit of tree growth is usually regarded as the natural boundary of the arctic zone, in the latter the trees becoming shrubs, while shrubs and herbs are much reduced in height. Plants in this zone usually have small leaves and well-developed roots, while large and brightly coloured flowers are common.

Importance of Extremes of Temperature.

Although the above suffices to illustrate in a general way the importance of temperature as a factor influencing the distribution of plants, it must be borne in mind that the mean annual temperature is very much less important than the extremes of temperature in any locality, and also that the effect of a certain temperature on a particular plant depends largely on the season of the year and the stage of development of the plant. Some plants require high temperatures throughout the year, others uniformly cold temperatures, while yet again others require high temperatures at certain seasons and low temperatures at others. Thus although the temperature in a given locality may be

sufficient for the germination of the seed and subsequent growth of a particular species, it may not be sufficiently high to enable the plant to produce fertile seeds, and hence, its distribution by seed being prevented, its chances of naturally establishing itself are small. The facts that luxuriant vegetation is characteristic of the hottest areas in the tropics, provided there is sufficient moisture, and that good forests exist in the coldest known spots of the earth, *i.e.* in parts of Siberia, suffice to show that other factors besides temperature are responsible for the distribution of plants, and for the absence of trees in parts of the tropics and in the arctic zone. Since a similar reduction in temperature may be caused, not only by increasing latitude, but also by increasing elevation above sea-level, we should expect, on ascending mountains, to find characteristic zones, or regions, of vegetation resembling those met with when proceeding from the equator towards the poles, and, to a great extent, this is the case. It must, however, be remembered that, although temperature is often the dominant factor influencing the distribution of plants in both cases, on mountains the increasing rarefaction of the air has an important effect on the climate and therefore on the vegetation, which is not the case in the lowlands.

Low Temperature due not only to increasing Latitude but also to Elevation above Sea Level.

Under temperature, also, we must not only consider the temperature of the atmosphere but also that of the soil, seeing that, when the soil temperature falls below a certain point, the roots are no longer able to absorb the necessary supplies of water and salts from the soil. If, while the roots are thus inactive, the leaves are actively transpiring moisture under the action of bright sunlight and dry air, the plant must suffer from desiccation, as has already been pointed out in *Part V* above, see page 211. Shallow-rooted, low plants, such as grasses, on the whole probably suffer less in this respect than do trees.

Importance of the Temperature of the Soil.

In the case of the former, as the temperature rises and transpiration increases, the roots situated in the superficial layers of soil are soon warmed sufficiently to enable them to make good the loss, while the tree roots situated in the deeper layers of cold soil are unable to do so. Moreover low plants, with their ærial portions situated in the calm, damp, lower layers of the atmosphere, do not transpire so actively as do the crowns of trees fully exposed to the action of drying winds. This factor is of great importance in high mountains where, owing to the short vegetative season, many trees find it necessary to remain in leaf throughout the year, their roots being in winter

buried in frozen soil and their crowns exposed to drying winds, and it is in fact mainly responsible for the absence of trees in the arctic zone and at high elevations. The temperature of the soil depends partly on its physical properties, sand possessing a far greater capacity for becoming heated, for instance, than clay; partly on its depth, the deeper layers only being affected by prolonged winter cold or summer heat; partly on the aspect, and partly also on the presence or absence of vegetation and the character of such vegetation.

Temperature is the principal factor determining the distribution of the valuable Hill Forests in India containing the Deodar and other important Conifers and Oaks. It also appears to be largely responsible for the distribution of Teak, no good natural forests of this species occurring north of cold-weather (*i.e.*, November-February) isotherm 65°. An important Indian tree which appears to require high temperatures throughout the year is the Red Sanders (*Pterocarpus santalinus*).

(4) Light. Effect of Light.

201. It has been noted in *Part V* above, see page 214, that light may injure plants by being (*a*) too intense or (*b*) too feeble. On high mountains the light is more intense than in the lowlands and is of importance in regulating the distribution of plants at high elevations. On the other hand the too feeble light makes it impossible for many plants, *e. g.* grasses, to live in the undergrowth of a dense forest, while a heavy growth of grasses may in turn, by preventing the access of light, be responsible for the death of tree seedlings. Many of our most important Indian trees require a great deal of light and cannot grow well in the shade of other plants, such as Teak, Sissoo (*Dalbergia Sissoo*), Khair (*Acacia Catechu*), Babul (*A. arabica*), Blue Pine (*Pinus excelsa*), and the Chir (*P. longifolia*), while others can stand a considerable amount of shade, *e. g. Xylia dolabriformis*, Sal and Sain.

(5) Air. Humidity of the Atmosphere

202. The humidity of the air is of great importance for plants, inasmuch as (1) the supply of water in the soil obtained from rain, dew, snow, hail and from the condensation of aqueous vapour depends upon it, and (2) it regulates the degree of transpiration from the ærial parts of plants (transpiration ceasing in saturated air and increasing in dry air) and of evaporation from the soil. Radiation of heat is also slower in moist than in dry air. As noted in *Part V* above, see page 215, winds may injure plants directly by uprooting, breaking and rending them, and also indirectly by increasing transpiration. The second mode of action is particularly

Action of Winds.

injurious at high elevations and may there be sufficient to prevent the existence of trees. Winds, by distributing pollen, aid in the fertilisation of flowers and production of seeds, and also help in the distribution of seeds. Grasses are thus particularly favoured in windy localities and so are conifers among trees. The fact that the light, large-winged seed of the Blue Pine is distributed further by the wind than is the seed of the Deodar is one of the causes which handicap the latter in its struggle for existence with the former. Finally the presence of poisonous substances in the air may make it impossible for some plants to survive in certain localities, *e.g.* in smoky towns, near Iron Works, or Chemical Factories.

Presence of Poisonous Substances.

(6) Existence of other Plants. Dependence of many Species on other Plants for their Existence.

203. The Forester in India knows from experience that, if he wishes to create forests of some of his valuable species, he must in the first place establish on the area a growth of other plants under the shelter of which his valuable species can be successfully introduced, whereas in the open their existence, at all events when young, would be impossible. This question of dependence on other plants may often decide which species shall survive in a given locality. On hot dry aspects, for instance, shelter during youth is essential for Deodar, which in such situations usually establishes itself naturally under the shade of species of *Indigofera*, *Desmodium*, and others. The seedlings of the Blue Pine on the other hand grow readily in the open and, in this respect, this species is favoured in its struggle for existence with the Deodar. The Sal also usually establishes itself best in open grassy areas if it is preceded by a growth of shrubs of inferior species, such as *Mallotus philippinensis*, and others, under the shade of which the young Sal are able to exist, a phenomenon which may be often seen on the edges of grassy blanks where the Sal forest is gradually extending and encroaching on the grassland. A very interesting case on record in this connection is that of the Bhinga Forest of the Bahraich Division of Oudh. In 1875 this was practically a ruined Sal forest, very open with no Sal regeneration; closure to grazing and the encouragement of a growth of *Mallotus philippinensis* and other shrubs has gradually resulted in the establishment of a growth of young Sal. An even more remarkable case is afforded by the Spruce and Silver Fir forests of the North-Western Himalayas. Here the natural reproduction of these species is usually conspicuous by its absence, and if a clearing is made, instead of good fir regeneration taking place, the ground is at once occupied by

brambles, willows, poplars, and other plants. After such plants have occupied the ground for some time, reproduction frequently reappears beneath their shade and again establishes itself on the area, the inferior species thus appearing to have prepared the way for the Spruce and Silver Fir and to have made their existence once more possible.

Although in all these cases it is obvious that certain plants are in some way helped by, and are in a measure dependent for their existence on, others, the exact way in which this help is given is by no means always clear.

In some cases mere shade from intense light may be the beneficial factor. In other cases the shade may be beneficial on account of its effect on the temperature of the plant and soil, and on the quantity of available moisture in the soil and air. In other cases again the benefit may consist solely in the fact that the shade has been sufficient to prevent the growth and development of injurious plant competitors, as would appear to be often the case when shrubs prepare the way for trees by killing out grasses.

It has been often thought that plants during life continually excrete poisonous waste products, the accumulation of which in the soil might render impossible the continued existence either of the same species or of other plants and that therefore some plants were able to poison the plants they displaced and that others even made their own existence impossible after a certain period. Although in the case of the higher plants this has not yet been proved, still it does undoubtedly hold good in the case of many fungi and bacteria. In the case of a particular tree therefore occupying a given area for a long period, it is possible that the accumulation of substances excreted by fungi and bacteria in the soil may render impossible the existence of those symbiotic fungi and bacteria which are employed in breaking down the humus, in which case the soil may become so impoverished that it can no longer support a crop of the tree in question, see also the remarks on page 95 in connection with the rotation of crops and also those on page 207. Similarly the existence of the symbiotic fungi which form the so-called mycorhizas may be prevented for a time, and the natural regeneration of certain tree species consequently rendered impossible. Any factor injuriously affecting these symbiotic organisms, such as insufficiency of oxygen or water, excess of water, too low a temperature, absence of sufficient organic food materials, and so on, would obviously produce the same result.

Enough, however, has now been said to show that the presence of an injurious plant parasite, or competitor, or the absence of a useful symbiont, may suffice to prevent the existence of a given plant in a particular locality, and hence it will be seen how necessary it is to avoid generalisations and to study in detail the case of each individual species in different localities. The valuable Sandal tree, we have seen above, depends to a large extent on other plants for its supply of water and mineral salts, and the existence of such plants is undoubtedly an important factor influencing the distribution of this tree.

(6) EXISTENCE OF OTHER PLANT.

(7) EXISTENCE OF ANIMALS. Injurious and Useful Action of Animals.

204. In India examples of forests which have been practically ruined by excessive grazing are not uncommon. In such areas species which are readily eaten by cattle are rapidly exterminated, all young growth being destroyed and there being, in consequence, no young stems to replace the mature trees which must sooner or later die. Goats are particularly destructive, and in areas continually browsed by them, the forest is frequently reduced to a scrub of scattered thorny shrubs and small trees, which alone are able to survive. Some of our important trees are not readily eaten by goats, and this fact has considerably affected the distribution of such trees as *Pinus excelsa*, *Terminalia tomentosa*, and *Butea frondosa*. *Xylia dolabriformis* is also an important tree which is, as a rule, little eaten by cattle. On the other hand, insects and birds are largely instrumental in helping plants to exist in certain localities by pollinating their flowers, while birds and other animals are often the most important agents for scattering seeds. Many species of plants may thus have their areas of distribution confined to that of definite insects, birds, or other animals. Red Clover is a well-known instance; this plant, being exclusively pollinated by humble bees, is only able to form fertile seed where humble bees exist. In India the flowers of *Butea frondosa* are largely pollinated by the rose-coloured starling (*Pastor roseus*); the seeds of species of *Loranthus*, *Ficus*, *Morus*, and of the Sandal tree are chiefly distributed by birds, while jackals are believed to be largely responsible for distributing the seed of species of *Zizyphus*. The seeds of Babul also are said to germinate best after they have passed through goats. From such instances it is obvious that the presence of an injurious parasitic, or the absence of a useful symbiotic, animal may suffice to explain the absence of a particular plant in a certain locality.

(8) Fire. Effect of FIRE.

205. If grasslands are burnt many of the most valuable fodder grasses, which are delicate annuals, are killed out and only the coarser species remain. Fires also,

by destroying seed, seedlings and young growth, may in time reduce a good forest to open grassland. Here, however, as in the case of all other factors influencing the distribution of plants, when studying their effect on a particular species of plant, we must consider not only their direct effect on that plant alone but also their effect on all those organisms which influence the development of the plant concerned. Thus protecting a forest from fire with the object of favouring the development of a particular species may have very unexpected results; for the growth of injurious competitors may be so much favoured by the fire protection as to enable them to oust the species it was desired to protect. This is reported to have occurred in certain fire-protected forests in Burma, where the teak is in danger of being ousted by some species of bamboos.

(9) ACTION OF MAN. Injurious and Helpful Action of Man.

206. On the one hand, man is responsible for the absence of forest trees over enormous areas which have been cleared for cultivation, or more gradually devastated by reckless fellings, fires and excessive grazing; on the other hand, he helps many plants to extend their range of distribution and to establish themselves in areas they could not have reached without his intervention. *Lantana aculeata*, for instance, a native of America, has been established in Ceylon and India. *Anona squamosa*, also, introduced from the West Indies, is now wild in many parts of India, and several other instances might be given.

Necessity of avoiding Hasty Conclusions as to the Factors responsible for the Distribution of any Plant.

207. There are thus a large number of factors which influence the distribution of plants, and hence we must guard against hastily ascribing to any one factor a result which may be due to the combined action of several, and against concluding that the factor, which appears most obvious, is primarily responsible for the distribution of any particular plant. Thus the fact that Salai (*Boswellia serrata*) is usually found in barren places where the soil is very poor and shallow must not lead us to conclude that this tree requires such soil for its development and cannot thrive on any other. As a matter of fact Salai will grow well in good deep soil, but in nature it is ousted from such localities by stronger competing trees which there find suitable conditions for their development, the result being that Salai is driven into the barren spots where it can exist, but where the majority of other trees cannot. Thus the fact that in nature Salai is, as a rule, only found on very poor rocky soil is due not, as might be supposed, to Salai's preference for such places, but to the presence of injurious competitors in

others. Similarly the fact that the Cocoanut tree (*Cocos nucifera*) in nature usually occurs on the saline soil of the seashore formerly led to the belief that the tree required a large quantity of salt in the soil. The fact that this tree grows well in gardens on ordinary soil, however, disproves this, and we are driven to the conclusion that the tree can only thrive in nature on saline soils owing to the fact that, in such localities, the majority of other plants cannot exist, and that it is driven out of more favourable localities by stronger competitors.

Power of Adaptation to Different Conditions

208. Another important point concerning plant distribution is the fact that most plants possess a considerable power of adapting themselves to a new environment, to changed conditions of existence. We very often hear, for instance, of plants which have become *acclimatised*. Some species possess this power in a high degree, others are less adaptable. It must be remembered that a plant which thus adapts itself to new conditions undergoes a more or less fundamental change, acquires as it were a somewhat different constitution, and this may, or may not, be manifested by an obvious change in its outward form, or habit. We have already seen, in *Part V* above, that certain individuals of one and the same fungus nourished by different hosts may differ essentially from one another although they cannot be distinguished by any visible character, see page 199. This undoubtedly also occurs in higher plants, but in many cases also remarkable changes are noticeable, some of which have been already mentioned under variations in *Part IV* above, see pages 152—155. In some cases plants show the change they have undergone by flowering and leafing at different periods of the year, or by becoming more or less deciduous, or evergreen.

Xerophytes. Hygrophytes, and Tropophytes.

209. A plant which is adapted to thrive in a locality where very little water is available is termed a *xerophyte.* Such plants are usually provided with a large and well developed root-system and with devices for preventing excessive loss of moisture by transpiration. Thus they frequently have small leaves (the transpiring surface being thus reduced), which are coriaceous, or fleshy, with a thick-walled epidermis, and often provided with a protecting covering of hairs, etc. They also often possess water-storing tissue. They are often provided with thorns, or spines, and sometimes with mobile leaflets which close up in strong sunlight. *Hygrophytes,* on the other hand, are plants adapted to thrive in a locality where an abundance of water is always available. They are usually provided with contrivances for accelerating trans-

piration, oversaturation of the tissues with water being the chief danger to be guarded against in this case. *Tropophytes* are plants which at one season of the year are xerophytes and at another hygrophytes; such are many trees in the deciduous forests of India which are hygrophilous in the rains and xerophilous at other seasons. A plant growing in a soil containing abundance of water need not necessarily be a hygrophyte; the water may for instance consist of a concentrated solution of salts, in which case the roots can only obtain the necessary supply of water and salts slowly and with difficulty. A xerophilous structure is thus necessitated. Such a structure may be due to any factor which either favours transpiration or interferes with the ready absorption of water from the soil by the roots.

## Chapter II.—PRINCIPAL TYPES OF VEGETATION.

210. The vegetation of the earth may be broadly divided into three great types :— **Types of Vegetation.**

(1) *Woodland* in which woody plants predominate.
(2) *Grassland* in which grasses predominate, usually in company with other herbaceous plants.
(3) *Desert* where the climatic conditions render luxuriant vegetation of any kind impossible and only a few plants are able to survive.

Grassland containing isolated trees is usually called *savannah*. Of each of these great types a multitude of varieties exist which however do not concern us at present. The distribution of the above types is influenced chiefly by three factors, *viz.*, (1) *Moisture* which depends principally on the amount and distribution of the rainfall, (2) *Soil* and (3) the *Action of Man*. These will be shortly considered below : **Factors influencing their Distribution.**

211. Typical deserts are characteristic of areas with a very small rainfall. Grasses, being usually shallow-rooted plants, depend mainly on the moisture in the surface soil. Typical grassland, therefore, can thrive if the rainfall is sufficient to keep the surface soil moist in the vegetative season. The majority of trees on the other hand depend mainly on the water in the subsoil and therefore require a rainfall sufficiently great to keep the subsoil permanently moist. No more remarkable instance of the dependence of vegetation on moisture can perhaps be given than that quoted below :— **(1) Moisture. Different Degrees of Moisture produce Desert, Grassland, or Forest**

" The station of Jacobabad is a striking example of the effect of water supply in that climate. It was founded in 1844 by General Jacob, in the midst of a barren, treeless desert. A canal was led to it from the Indus, and now the plain is a dense forest of babool and other trees, upwards of sixty feet high, sheltering the houses and gardens of the inhabitants. A ride of a few miles takes you into the desert which skirts the hills of Beloochistan, a level plain of splendid, fertile, alluvial soil, but hard, naked, and barren, like a threshing floor, without shrub, herb, or grass, except in the vicinity of the canals, where vegetation is rich and luxuriant. " *

It has been noted above that in mountains the greatest rainfall usually occurs at a comparatively low elevation and

* Sir Dietrich Brandis *op.* ., p. 11.

becomes less as the elevation increases. Hence in high mountains, also, the effect of moisture on the vegetation may often be clearly seen. On the lower slopes with a heavy rainfall we find forests, at higher altitudes grassland and finally, if the line of perpetual snow does not extend to the grassland, desert. As already noted also the quantity of water available for deep-rooted plants at high elevations depends not only on the amount of the rainfall but to a great extent also on the temperature of the soil.

(2) Soil.

Existence of Desert, Grassland, or Forests may depend on the Soil.

212. A study of the gradual changes in the soil and vegetation which may often be seen occurring in an area covered with naked rock, before luxuriant vegetation finally establishes itself there, demonstrates very clearly the dependence of the type of vegetation on the soil. The rocks are first weathered and broken up, slowly it may be but none the less surely, by the mechanical action of heat and cold and the chemical action of the atmosphere and water. On the decomposing rocks and rocky particles small algæ and lichens usually soon establish themselves. Lichens aid in the work of decomposition by keeping the rock surface moist and by the action of their absorbing hyphæ. The decaying remains of such plants, mixing with the particles of rock, produce a little soil on which mosses, grasses, and other higher plants can establish themselves. In cracks and clefts in the rock also where more soil accumulates than elsewhere, woody plants soon appear which by the action of their roots play an important part in the disintegration of the rock and in the formation of new soil. Many trees and shrubs which in themselves may not be valuable on account of their timber or other products are for this reason of the greatest value to the Forester, they being the pioneers which prepare the way for more valuable species and make the existence of the latter possible. Among such pioneer plants should be noted the very common and widely distributed Salai (*Boswellia serrata*) and Kulu (*Sterculia urens*). As this preparatory work proceeds and the accumulation of soil increases, more and more trees succeed in establishing themselves, and eventually woodland arises where at first there was only barren rock. Thus here, as the naked rock becomes converted at first into shallow and later into deep soil, we can trace corresponding changes in the vegetation, the desert at first passing into grassland, while the latter eventually gives way to woodland. It is important for the Forester to realize the part played in nature by the pioneer plants noted

Pioneer Plants.

above for, on the one hand, much money has been uselessly spent in parts of India on sowings and other operations with the object of forestalling the slow operations of nature by quickly afforesting areas occupied by pioneer plants with more valuable forest trees and, on the other hand, cases have occurred where the premature wholesale removal of such pioneers has retarded the natural evolution of valuable forest by many decades.

From what has been said above we see that a virgin forest, in a sense, represents the final product of centuries of work on the part of nature, the final result of countless struggles in which only those plants survived and for a time occupied the ground which were able to exist under the conditions of the environment prevailing at the time. At first, the absence of a suitable nutritive substratum rendered impossible the existence of the majority of plants, and minute algæ and lichens were left in undisturbed possession. Later, the accumulation of humus soil which could retain a sufficient quantity of moisture allowed grasses and herbaceous plants to obtain a footing, and they ousted the algæ and lichens. Finally, a still deeper soil with moist subsoil enabled woodland to vanquish the grassland. The first plant settlers have to struggle against the very unfavourable conditions of the non-living environment, while later arrivals have to face a keen fight for existence against other competing plants. The scientific Forester, it is true, has to interfere with the operations of nature to a certain extent, since it is his business to see that the most valuable plants, from his point of view, are favoured as much as possible in the struggle for existence. At the same time this power can only be usefully exercised within very definite limits and the interference to be useful must be intelligent and exercised so far as possible in the light of a good knowledge of the principal factors at work in each case. Man cannot, for instance, establish flourishing woodland in a locality which can only support grassland and by an unintelligent interference with the vegetation on an area he may reduce woodland to a desert.

Succession of different Plant Generations or Crops.

Succession of Plant—Communities on alluvial deposits in Sub-Himalayan Tract.

213. A phenomenon analogous in many respects to the succession of different types of vegetation noted above may often be seen in the Sub-Himalayan tract of India. Here on the banks of boulders, shingle and sand brought down by the rivers the first arrival is frequently *Dalbergia Sissoo* which in such places forms gregarious forests. This species with its deep and far-reaching root-system helps to

fix and protect these "flood-plains," as they are sometimes called, against the action of subsequent floods, while the soil is gradually enriched by the accumulation of organic débris. Sissoo, being a light demander, the forests of this species thin out and become open with increasing age, thus leaving room for various miscellaneous species which soon establish themselves and eventually, ousting the light-demanding Sissoo, give rise to a mixed forest of inferior species. As time goes on however and the soil is still further improved by the accumulation of humus and by the continued shelter from climatic influences, the struggle for existence between the competing trees becomes more severe, more trees finding on it congenial conditions for their development, and cases may often be seen on the older alluvial deposits where the Sal, partly owing to its capacity of withstanding the injurious effects of a considerable degree of shade, has been able not only to obtain a footing in the mixed forest but to entirely oust other miscellaneous species and to form pure forests of its own.

Action of Man in Altering the Ordinary Course of Natural Events is necessarily Restricted.

214. From these two instances the important part played by plants themselves in forming soil and in altering its physical and chemical properties is clearly recognized, and we see that some plants are able to create the conditions necessary for the existence of others; this part of the subject, however, has been more fully discussed in *Chapter I* above under *Existence of other Plants*, see pages 225, 226. Cases such as these also show us that in nature a particular type of vegetation is not always able to maintain possession of an area for an indefinite period, and that an area carrying a good forest of a particular species may not necessarily be able, in the natural course of events, after the removal of that crop, to at once produce a second crop of the same species. Further we must remember, as already stated above, that although man can to a certain extent interfere with and alter the process of natural development yet his power in this respect is limited.

(3) Action of Man. Existence of Desert, Grassland, and Forest often depends on the Action of Man.

215. Several cases are on record in India in which man, by destroying the forest growth on hill-sides, has reduced woodland to desert, and the Forester is often now employed in the difficult task of inducing vegetation to re-establish itself on the barren, rocky slopes and of transforming the desert once more into woodland. In many cases, however, the destructive influence of man has not proceeded so far, and his action has resulted in establishing grassland where flourishing forests once existed. Throughout

India such instances are extremely common, the forest having been first cleared for cultivation and grassland now occupying the abandoned fields. It has been well said that: "woodland and grassland stand opposed to one another like two equally powerful but hostile nations, which in the course of time have repeatedly fought against one another for the dominion over the soil,"* and nowhere does the Forester perhaps realise the truth of this more strongly than in India. The seedlings of many of our most valuable tree species, in the first year or two of their existence, may only attain a height of a few inches above the ground and have no chance of surviving in the struggle for existence in a dense mass of grasses which effectually shut out the necessary light.

**Conversion of Grassland into Forest.**

216. In many parts of India the afforesting of these grass lands is one of the most difficult problems which the Forester has to solve. The difficulty of the task, moreover, is often increased by the fact that these clearings were frequently made in the middle of dense forests. Tall tree-growth therefore, in such cases, surrounds the clearings like a wall which, by interfering with the free circulation of air, is largely responsible for the grassy area becoming what is known as a *frost-hole*, where only the most frost-hardy species can exist. In many cases it has been noticed that if such grasslands are protected from fire and grazing they become in time naturally reconverted into woodland. At first small grasses form a dense mantle completely covering the ground and hiding it from view; the grass-crop then becomes gradually thinner, and the small species are replaced by taller, coarser grasses, under the shade of which patches of unoccupied soil are visible. Between these grasses a growth of shrubs then creeps in, the shade of which while sufficing to kill off the grasses still allows the seedlings of many tree species to establish themselves. Finally the thinning out of the shrub growth allows these seedlings to develop, and the area becomes once more covered with forest. That this process has occurred and is still in operation in many of our fire-protected forests there can be no doubt, but at the same time the process is often exceedingly slow. Various plans have been resorted to in different parts of India with the object of hastening the naturally slow progress of events. In some cases the seeds of tree species are sown with low-growing field crops, the injurious competitive action of which is less injurious than that of the wild

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* *Plant Geography* by Dr. A. F. W. Schimper, Eng. Edn., 1903, p. 162.

grasses, while the cultivation prevents the development of such grasses. In other cases grazing has been allowed with the object of keeping down the grass-growth until the tree-seedlings have become established, and elsewhere, quick-growing, accommodating tree-species have been introduced artificially into the grassland in the hope that they will oust the grasses. Providing the soil is suitable, the greater the rainfall, the more quickly as a rule does woodland reassert itself in India on grasslands from which the forest has been cleared, and *vice versâ.*

Trees producing Root-suckers Favoured in the Struggle with Grasses.

217. Root-suckers which are capable of attaining a height of several feet in one year are obviously more able to hold their own in such grasslands than are minute seedlings, and species which reproduce themselves readily by root-suckers are thus often able to successfully conquer the grasses in such areas. Evidence of this is often seen in India in the practically pure forests of *Ougeinia dalbergioides* and *Diospyros tomentosa* which now occupy the sites of old abandoned fields.

## Chapter III.—PRINCIPAL TYPES OF INDIAN FORESTS.

218. For the purposes of a brief and general description the forests of India may be divided broadly into the following types :— Types of Forests.

(1) Arid-country Forests.
(2) Deciduous Forests.
(3) Evergreen Forests.
(4) Hill Forests.
(5) Tidal or Littoral Forests.

It must be remembered that as each type of forest often passes very gradually into a different type, the boundary line between the various types cannot always be clearly defined; moreover differences in the soil, local conditions affecting the amount of moisture available, and other factors may entirely alter the type of forest over small areas, which cannot be taken into consideration in a broad and general account. The approximate distribution, however, of these types is shown in *Plate XXII* areas bearing no forest not being separately shown. In each of these main types also numerous sub-types of course exist which it is impossible to note in detail here. The principal factor responsible for the distribution of types 1 to 3 is the amount of available moisture as measured approximately by the annual rainfall, which is clearly shown by a comparison of *Plates XXI* and *XXII* ; type 4 owes its existence mainly to low temperature caused by the elevation above sea-level, while type 5 is due mainly to the large quantities of salts dissolved in the sea-water and to the action of the tides. Factors responsible for their Distribution.

219. The principal tract of country which, with reference to its rainfall, may be called arid, the annual rainfall being less than 20 inches, occurs in the North-Western corner of India, including Sindh, the southern portion of the Panjab, and a large part of Rajputana. A large portion of this area is occupied by desert, the principal woodlands being the so-called *rakhs* of the Panjab in the north and the belts of the riverside forest along the Indus and its main tributaries. The rakhs occupy the high ground between the rivers and are poor, scanty woods of small trees and shrubs, the most characteristic species being *Prosopis spicigera* and species of *Salvadora* and *Capparis*. Owing to the great depth of the subterranean water the species occurring in these rakhs are often characterised by possessing roots of immense length and a taproot of *Prosopis* measuring 86 feet in length has been exhibit- (1) Arid-country Forests.

ed. The riverside forests occupy the alluvial soil watered by the rivers, either by percolation, or by the annual floods, and they owe their existence to the supply of moisture thus obtained. The principal species are Babul (*Acacia arabica*), *Populus euphratica* and species of *Tamarix*. Both the babul and the poplar occur more or less pure over considerable areas and at other times as standards over an underwood of *Tamarix*. These forests are often washed away as the river changes its course, and the fresh alluvial deposits thrown up by the river are quickly covered with a dense growth of seedlings. This arid region occupies the extreme eastern end of the great belt of desert which stretches from Northern Africa, through Arabia, South Persia and Baluchistan, to beyond the Indus. The comparatively small number of species occurring in it is a noticeable feature, and it is also remarkable that some of them occur both in the African and Indian area, *e.g.* *Salvadora persica* and *Capparis spinosa*. The forests of this arid Indian region become richer in species towards the north and east, passing then gradually into deciduous forests. Towards the east *Anogeissus pendula* is a common and characteristic species, it being the chief forest tree in Meywar and Merwara.

(2) Deciduous Forests.

220. A reference to the map *Plate XXII* will show the enormous area which is included in the region of the deciduous forests which, with reference to its rainfall, may be called the *moist* Indian Region, the annual rainfall ranging from 20 to 70 inches. These are commercially the most valuable forests of India, including as they do the greater part of the Teak and Sal forests, besides other valuable species such as the Sandal, Red Sanders, Sissoo and many others. In the drier regions this type of forest merges into arid forest and in moist localities into evergreen forest, but on the whole the growth, while better than that in the arid forests, is not so luxuriant, and the trees do not attain such large dimensions as in the evergreen forests. In the deciduous forests the great majority of the trees are deciduous in the dry season. While a large number of species are found almost universally distributed in this type of forest, others are confined more or less to local areas. Among the most widely distributed species are the following :—

*Terminalia tomentosa* (The Sain or Saj, usually on clayey soil).
*Terminalia belerica*.
*Terminalia Chebula*.
*Lagerstrœmia parviflora*.

*Butea frondosa* (Palas).
*Bombax malabaricum.*
*Buchanania latifolia.*
*Adina cordifolia.*
*Stephegyne parvifolia.*
*Ægle Marmelos.*
*Cassia Fistula.*
*Acacia Catechu* (The Khair, often gregarious on 'flood-plains' and scattered in dry forest).
*Albizzia odoratissima.*
*Bauhinia racemosa.*
*Bauhinia variegata.*
*Erythrina suberosa* (in dry forests).
*Eugenia Jambolana* (in moist places and along river banks).
*Ficus glomerata* (in moist places and along river banks).
*Ficus hispida* (common in shady moist places).
*Ficus infectoria.*
*Flacourtia Ramontchi* (on dry hills).
*Gardenia turgida* (in dry, rocky places).
*Grewia asiatica.*
*Holarrhena antidysenterica.*
*Hymenodictyon excelsum* (in dry forests).
*Kydia calycina.*
*Phyllanthus Emblica.*
*Schleichera trijuga.*
*Schrebera swietenioides.*
*Stereospermum suaveolens.*
*Garuga pinnata.*
*Zizyphus Jujuba.*
*Zizyphus Œnoplia.*
*Zizyphus rugosa.*
*Boswellia serrata* (not in Burma) } on dry rocky hills.
*Sterculia urens.* }
*Odina Wodier* ( in dry forests).
*Careya arborea.*
*Bassia latifolia* (the mahua).
*Dendrocalamus strictus.*
*Phœnix humilis.*
*Anogeissus latifolia* (not in Burma).

Among climbers the commonest are—

*Butea superba.*
*Bauhinia Vahlii.*

*Acacia pennata.*
*Acacia caesia.*
*Cryptolepis Buchanani.*
*Vitis sp.*

Parasitic *Loranthaceae* are also very common in these forests. The limits of the distribution of some of the most important species of these forests, *i.e.* of Sal, Teak, Sandal and Red Sanders, are shown in *Plate XXIII.*

The Sal is strongly gregarious, and is by far the most numerous tree in the forests in which it occurs. In the Sub-Himalayan tract the Sal forests usually occupy the higher tracts of old alluvium lying between the rivers, while the more recent alluvium, consisting of beds of shingle and sand, in and near the river beds, is often covered with gregarious forests of Sissoo and Khair.

In damp places in the Sal forests, the Indian Red Cedar (*Cedrela Toona*), *Trewia nudiflora*, and *Pterospermum acerifolium* are common.

The Teak, unlike the Sal, usually occurs in mixed forests, where it frequently forms only a small proportion of the stock. Although the Sal and Teak areas meet in Central India and to a certain extent overlap, these trees are not found together. An isolated patch of Sal for instance occurs inside the Teak area, at Pachmarhi, in the Central Provinces. Teak is occasionally found practically pure on alluvial ground, but its best growth is obtained on well drained slopes. A large number of species found in the Indian Teak area are also found in the Teak forests of Burma and, besides those already mentioned, the Ironwood of Pegu and Arracan (*Xylia dolabriformis*) should be noted. On the other hand several species found in the Indian area do not extend to Burma and *vice versâ.* In the Indian area the following are important trees :—

*Pterocarpus Marsupium* (Bijasal).
*Pterocarpus santalinus* (Red Sanders).
*Hardwickia binata* (Anjan).
*Dalbergia latifolia* (Shisham, or Bombay Black Wood).
*Chloroxylon Swietenia* (Satin Wood).
*Ougeinia dalbergioides* (Sandan, or Tinas).
*Santalum album* (Sandal).

The Burman Teak forests on the other hand contain such species as—

*Dillenia parviflora.*
*Homalium tomentosum.*

*Cassia siamea.*
*Pterocarpus macrocarpus.*

Peculiar species of *Sterculia.*

And above all are characterised by possessing many different bamboos such as—

*Bambusa Tulda.*
*Bambusa polymorpha.*
*Cephalostachyum pergracile.*
*Dendrocalamus longispathus.*
*Oxytenanthera albociliata.*

In the Burman deciduous forest area also are found the so-called Eng, or In forests, usually on formations of laterite. *Dipterocarpus tuberculatus* is here the most characteristic tree with which occur the following :—

*Pentacme suavis,*
*Shorea obtusa,*
*Dillenia pulcherrima,*
*Dalbergia cultrata,*

and others. The well-known Andaman Padauk tree, *Pterocarpus dalbergioides*, is found in the Andaman Islands, usually in deciduous forests.

(3) Evergreen Forests.

221. These are found, as will be seen from the maps, in the wet region which has an annual rainfall exceeding 70 inches. They are in their characteristics the most essentially "tropical" of our Indian forests. They are especially remarkable on account of the large number of evergreen species which they contain, their luxuriant vegetation, and the enormous dimensions attained by some of their trees. A rich growth of giant climbers (lianes) and of epiphytes usually covers the stems of the trees, and the undergrowth is frequently so dense as to be practically impenetrable. The number of species is very much greater than in the deciduous forests. The general characteristics of this class of forest are excellently described in the following passage :—

"In a tropical evergreen forest, growing under favourable conditions, we find four storeys of vegetation. Immediately covering the soil are seedlings mixed with shrubs and herbaceous species and in the next zone, or storey, small, or medium-sized evergreen trees 50—75 feet high. The top canopy of great evergreens, often 150 feet above the ground, is crowned by giant, sometimes deciduous, trees, of which *Tetrameles nudiflora* is one of the most common and remarkable. The tree stems are in many instances covered with epiphytic Utricularias, Orchids,

Aroids, and Ferns. In North Kanara where the evergreen tropical Kans ( a local name for evergreen forests) are contiguous to, or surrounded by, mixed deciduous forest the divergence between the classes of vegetation is very striking. There is considerable physical relief in passing abruptly from the strong glaring sunlight of the open deciduous jungle in the hot season to the cooler atmosphere and deep, somewhat gloomy, shade of the lofty evergreens. The bewildering diversity, height and size of the trees, the universal green and general absence of colour, the great climbers with fantastic shaped stems, the epiphytic orchids, aroids, and ferns, the general stillness and apparent absence of animal life, appeal to the naturalist, who is satisfied that here at least the action of man has not affected and changed the original flora of these truly primeval forests. The principal forces of nature are in constant action, and there is no annual period of rest, corresponding to the winter in temperate and arctic regions or the hot seasons in the dry tropics. On the shady, moist, well-covered soil, the growth is continuous, and the struggle for existence amongst the many species in the zones of vegetation is very great. The principal causes preventing the predominance of any one genus or species over more than a limited area are to be found in the very favourable conditions in which this strongly differentiated and extremely rich flora is placed. * *

It is very difficult to correctly identify on the spot many of the high trees growing in the Kans. The rapid and continuous growth produces generally a thin, smooth, greyish bark with scarcely any rhytidome. The great height of many of the stems prevents examination of their foliage, the flowers are also often inconspicuous and appear at different seasons of the year. These, together with the diversity of the species, make a satisfactory interpretation of the flora almost impossible. In the smaller, less varied and more open deciduous forests such examination is not attended with similar difficulties. It is of common occurrence to see a tall tree in full bloom in the evergreens and to be unable to procure specimens of the flowers, except by felling or sending up a native climber, both usually very tedious operations. Much of the evergreen region of North Kanara is somewhat difficult of access, as the dense undergrowth often bars the way of the observer. The forest pathways are also usually bounded by monotonous walls of verdure, without the relieving colour of conspicuous flowers.''*

* *The Distribution of the Forest Flora of the Bombay Presidency and Sind* by W. A. Talbot. *Indian Forester*, Vol. XXXII, pp. 56—58.

Bamboos, being as a rule light-demanders, are usually absent in the evergreen forest although they are found along open water-courses, in clearings and on the borders of the forest. It is only possible here to mention a very few of the most characteristic and useful trees and genera found in this type of forest as follows :—

*Tetrameles nudiflora.*
*Alstonia scholaris.*
*Antiaris toxicaria.*
*Chukrasia tabularis.*
*Dipterocarpus.*
*Diospyros.*
*Dysoxylum.*
*Canarium.*
*Swintonia.*
*Sterculia.*
*Lagerstrœmia Flos Reginae.*
*Mesua ferrea.*
*Vitex.*
*Cedrela Toona.*
*Pterospermum.*
*Mangifera indica.*
*Calophyllum.*
*Myristica.*
*Artocarpus.*
*Ficus.*
*Cinnamomum.*
*Aporosa.*
*Memecylon.*
*Garcinia.*

It will be noticed that a few species found in the deciduous forests also extend into the evergreens, such as *Cedrela Toona.*

In many places an intermediate type of forest can be more or less clearly distinguished in which many species of the deciduous forests are found, but where the luxuriance of the vegetation rather resembles that of the evergreen forests. In such areas trees like Teak, *Xylia dolabriformis*, *Dalbergia latifolia* and *Terminalia tomentosa* are found and there attain large dimensions.

Among climbers of the evergreen forest many species of *Calamus* are common, while screw pines and palms are often met with, among the latter *Arenga*, *Caryota*, *Livistona* and *Licuala* being noticeable.

(4) Hill Forests. Hill Forests in North-Wes ern Himalaya.

222. The most important area of hill forest in British territory is situated in the North-West Himalaya, as will be seen from the map, *Plate XXII*. A brief description of the zones of forest traversed on ascending the Himalayas, starting, say, from Kalsi in the Dehra Dun and proceeding *viâ* Chakrata, will give a fair idea of the chief characteristics of this type of forest. The different zones of vegetation may be conveniently numbered serially as below, beginning with the lowest, it being of course remembered that the transition from any one zone to the next is often gradual and not sharply defined.

ZONE I.—Elevation 1500′—3000′.

SAL predominates, mixed with several species of the deciduous forests, such as *Terminalia tomentosa*, *Anogeissus latifolia*, *Ougeinia dalbergioides*, *Adina cordifolia*, *Odina Wodier* and others.

The Chir Pine (*Pinus longifolia*) also occurs as scattered trees, or in small patches, and the Sal here usually attains only small dimensions.

Common and characteristic species also in these outer hills are—

*Bœhmeria rugulosa*, *Bauhinia retusa* and *Engelhardtia spicata*.

ZONE II.—Elevation 3000′—6000′.

CHIR PINE predominates, mixed with small trees of Zone I at lower elevations and higher up with—

The Ban Oak (*Quercus incana*) *Rhododendron arboreum*, *Pieris ovalifolia*.

In valleys *Quercus glauca*, *Meliosma pungens*, *Albizzia Julibrissin*, *Rhus Cotinus*, *Celtis australis* and *Olea glandulifera* are common.

ZONE III.—Elevation 6000′—8000′.

DEODAR predominates, mixed with *Rhododendron arboreum*, Ban Oak, Moru Oak (*Quercus dilatata*), Blue Pine (*Pinus excelsa*), Spruce (*Picea Morinda*) and many broad-leaved trees such as *Betula alnoides*, *Populus ciliata*, Horse-chestnut, Walnut, Elm, Hazel, Hornbeam, Maples, and Holly. Among shrubs occurring in this zone are—*Berberis*, *Euonymus*, *Rhamnus*, *Abelia*, *Viburnum*, *Lonicera*, *Deutzia*, *Indigofera*, *Desmodium*, *Spiraea*, *Rubus*, *Rosa*, *Cotoneaster*, and *Salix*, Among climbers are

*Clematis*, *Holbœllia latifolia*, *Hydrangea altissima*, *Vitis semicordata* (Himalayan "Virginia Creeper") and the Ivy.

Above 7000 feet *Quercus dilatata* usually replaces the Ban Oak.

In this zone also occur—

The Cypress (*Cupressus torulosa*) often on limestone precipices.

The Box (*Buxus sempervirens*) usually on calcareous soil, but also on other kinds of soil in moist sheltered valleys.

The Yew (*Taxus baccata*) in shady places, but perhaps more often met with in the next higher zone.

ZONE IV.—Elevation 8000′—11000′.

KARSHU OAK (*Q. semecarpifolia*), which is often gregarious, predominates. In its zone are found the Spruce, Silver Fir (*Abies Pindrow*) and some broad-leaved species. *Rhododendron campanulatum* is also found which extends into the next zone.

ZONE V.—Elevation above 11000′.

WHITE BIRCH (*Betula utilis*) predominates, often with a tangled undergrowth of the shrubby, gregarious *Rhododendron Anthopogon*. In this zone also occurs another shrubby Rhododendron, *R. lepidotum*, and species of Juniper, *e.g.* *Juniperus recurva* on the northern slopes of Chansil.

Beyond the region of shrubs, if the snow-line does not intervene, we find grasses with Gentians, Edel Weiss (*Leontopodium alpinum*) and other herbs and then perpetual snow.

**Hill Forest of Eastern Himalaya, Assam, and Burma.**

223. A detailed description of the hill forests of the Eastern Himalaya, Assam, and Burma cannot be given here although botanically they are more interesting than the hill forests of the Western Himalaya. While some species, as might be expected, are widely distributed throughout the hill forests, others are more or less confined to local areas.

*Rhododendron arboreum* and *Taxus baccata* for instance are found throughout the Himalaya, in Assam, and in Burma. On the other hand each region possesses certain species of its

own, and those mentioned below are more or less confined to the regions shown :—

| Region. | Conifers. | Oaks. |
|---|---|---|
| Western Himalaya. | (1) Deodar. | (1) *Quercus dilatata.* |
| | (2) *Cupressus torulosa.* | (2) *Q. incana.* |
| | (3) *Pinus Gerardiana* (inner dry hills of the Himalayas and in Afghanistan). | (3) *Q. Ilex.* |
| | (4) *Abies Pindrow.* | |
| | (5) *Juniperus communis.* | |
| | (6) *J. macropoda.* | |
| Eastern Himalaya. | (1) *Tsuga Brunoniana* (Indian *Hemlock Spruce*). | (1) *Q. lanuginosa.* |
| | (2) *Larix Griffithii.* | |
| Assam. | *Cephalotaxus Mannii.* | (1) *Q. Olla.* |
| | | (2) *Q. xylocarpa.* |
| Burma. | *Pinus Merkusii* | (1) *Q. calathiformis.* |
| | | (2) *Q. Brandisiana.* |
| | | (3) *Q. Lindleyana.* |
| | | (4) *Q. eumorpha.* |

The following conifers are found both in the West and East Himalaya :—

*Pinus excelsa, Picea Morinda, Juniperus Wallichiana, Pinus longifolia, Juniperus recurva.*

*Pinus Khasya* is found in Assam and Burma, often forming pure forests with an undergrowth of grass.

*Quercus semecarpifolia* and *Q. glauca* are found throughout the Himalaya and also in Assam. Several oaks occur both in the Eastern Himalaya and in Assam, *e. g. Q. lamellosa, Q. pachyphylla, Q. spicata* and *Q. dealbata.*

Several also occur both in Assam and Burma, *e.g. Q. semiserrata, Q. mespilifolia, Q. polystachya, Q. truncata* and *Q. Helferiana.*

Common to the Eastern Himalaya, Assam, and Burma are—

*Q. serrata, Q. Griffithii, Q. fenestrata, Q. lineata,* species of *Castanopsis, Bucklandia, Machilus, Phœbe* and *Nyssa.* Noticeable features of some of the hill forests of the Eastern Himalaya are the occurrence of a large number of Rhododendrons, many of which are gregarious shrubs forming dense thickets, and

the presence of several magnoliaceous trees with beautiful flowers, *e.g. Magnolia Campbellii.*

(5) Tidal or Littoral Forests.

224. These forests are found on the mud-banks bordering the sea and tidal rivers. The trees are here never large, and the commonest species are those usually known collectively as *mangroves*, whence this type of forest is often called mangrove-forest. Owing to their peculiar environment, the plants in this class of forest have to contend chiefly with—

(1) The action of the wind, waves, and tides tending to uproot the trees growing in the soft mud.
(2) The excess of salts in the water around the roots.
(3) The difficulty of obtaining sufficient oxygen for their roots.
(4) The danger of having their seedlings submerged and killed by the rising tide.

We should therefore naturally expect that comparatively few species would be able to exist under these unfavourable conditions and that those which are able to survive would possess certain definite and well-marked characteristics.

In the littoral forests of India and Burma " the species of tree which forms the advanced line along the sea and which, by its slow forward march, causes a gradual elevation of the coast, is *Rhizophora mucronata.* No mangrove-tree is better equipped for resisting the movements of the tide on the soft mud, for propagating itself under these difficult conditions, and for recovering from the frequently quite undilute salt sea-water, the water lost in transpiration. The scaffolding of bow-shaped stilt-roots supporting the stem represents a complete system of anchors, which is strengthened by new roots growing down from the branches to balance the growth of the crown." (In other species of mangrove growing further from the sea these anchoring roots are less strongly developed or are altogether absent.) " The leaves possess a marked xerophilous structure with a thick cuticle. * * protected stomata, and especially a large-celled thin-walled aqueous tissue, the dimensions of which increase with the age of the leaf and with the corresponding rise in the amount of salt contained. Old leaves serve essentially as water-reservoirs for the younger leaves."*

* Schimper op. cit., p. 396.

In order to insure a sufficient supply of oxygen for the roots, many trees in these forests are supplied with so-called *pneumatophores*, or ærating roots. In some species these grow up from the ground and look like thick shoots of asparagus, in others the roots bend up out of the ground and form knee-like structures, while in some cases the upper surface of the roots alone projects above the ground. These ærial roots, or portions of roots, are usually covered with thin cork and possess abundant lenticels. "The mode of propagation is most remarkable in *Rhizophora mucronata*, which in this respect agrees in the main with the other *Rhizophoraceae* living in the mangroves. The fruit leathery and indehiscent and about the size of a hazel-nut, soon after the completion of its growth is pierced at its summit by the green hypocotyl, as the embryo does not undergo any period of rest, but continues to develop without interruption. The hypocotyl in *R. mucronata* is club-shaped and attains a length of 60 centimetres, sometimes even more, before it falls down, leaving behind it the fused cotyledons which served as absorbing organs. As its lower end is thicker, the seedling falls vertically, with its root-tip downwards into the mud, and within a few hours develops roots that fix it firmly."*

The principal genera in these forests are—

| | |
|---|---|
| *Rhizophora.* | *Carapa.* |
| *Ceriops.* | *Avicennia.* |
| *Kandelia.* | *Sonneratia.* |
| *Bruguiera.* | *Lumnitzera.* |

Among shrubs *Acanthus ilicifolius* (with leaves like holly and blue flowers) and *Ægiceras* are common.

The two small palms *Nipa fruticans* and *Phœnix paludosa* form gregarious thickets in the Sundarbans and littoral forests of Burma. Common climbers are species of *Derris*; epiphytes are scarce and there are usually no mosses. Ferns and grasses often form the undergrowth in the drier spots.

Further inland above high-tide mark, on ground which is only occasionally, if ever, flooded, the following are characteristic:—

*Heritiera Fomes.* The *Sundri*, which is the most important tree in the Sundarbans.

*Thespesia populnea.*
*Hibiscus tiliaceus.*

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* Schimper op. cit., pp. 396—398.

*Excœcaria Agallocha.*
*Cerbera Odollam.*
*Scaevola.*
*Clerodendron inerme.*
*Erythrina indica.*
*Pongamia glabra.*
*Casuarina equisetifolia.*
*Pandanus tectorius.*

**Riparian Forests.** 225. The principal types of Indian forests have now been considered in detail above, and it only remains to briefly mention the sub-type, often called *riparian forest*, which is found along the banks and in the beds of rivers and streams and in swampy places. Forests in such localities usually have an abundant supply of fresh water available in the soil, and consequently the belt of land immediately bordering perennial streams in the arid region may be able to support forest of the ordinary deciduous type, while similar streams in the zone of deciduous forests may be fringed with more or less evergreen forest. At the same time the conditions under which the plants of these forests exist are often peculiar in many respects.

The ground on which they grow is, for instance, often liable to more of less prolonged submersion in water at certain seasons which, by causing stagnation of water around the roots, may effectually prevent the latter from performing their functions on account of the want of sufficient oxygen. A very common species in riparian tracts is *Ficus glomerata* which sheds its leaves during the rainy season, possibly owing to the roots being then unable to perform their normal functions.

In addition to this also many of our Indian rivers and streams are entirely dry for several months in the year, when the sandy shingly soil in and near their beds becomes dried and excessively heated to a considerable depth. Other factors to be considered also are the action of floods in washing away the soil and exposing the roots and the utility of water as a seed distributor, those species possessing devices favouring this mode of seed-dispersion having an advantage in the struggle for existence in riparian tracts, as has been noted above in the case of Sissoo and Khair. It is therefore not surprising that many species which are characteristic of riparian tracts, are not often found elsewhere. Among such may be mentioned—

*Anogeissus acuminata.*
*Barringtonia acutangula.*
*Eugenia sp.*

*Ixora sp.*
*Tamarix sp.*
*Pongamia glabra.*
*Trewia nudiflora.*
*Terminalia Arjuna.*
*Ficus hispida.*
*F. glomerata.*
*Homonoia sp.*
*Salix tetrasperma.*

As indicating that the plants in these forests often find it difficult to obtain their necessary supply of moisture, it is noticeable that *Anogeissus acuminata* and *Eugenia Heyneana*, which are common riparian species, are characterized by being small-leaved species of their respective genera, small leaves being as a rule very characteristic of xerophytes, while several plants which occur in riparian tracts are also often found in very dry localities, *e.g.*—

*Anogeissus acuminata* (occasionally),
*Vitex Negundo*,
*Streblus asper*,
*Acacia Catechu*,
*Balanites Roxburghii*,
*Capparis aphylla*,

and others.

An interesting and perhaps one of the most widely distributed plant characteristic of dry river-beds is *Rhabdia lycioides*, with its minute leaves and creeping, rooting branches which enable it to withstand successfully the action of violent floods.

Distribution of Important Forest Species.

226. The distribution of all important Indian trees, so far as it is at present known, is given in detail in Brandis' *Indian Trees* and in Gamble's *Manual of Indian Timbers* and will not be repeated here. The approximate limits of the distribution of Teak, Sal, Deodar, Sandal, Red Sanders and Caoutchouc have, however, been indicated in the map, *Plate XXIII*.

The principal factors responsible for the distribution of the chief types of forest have been given above, and in a few cases the factors which appear to have a considerable influence on the distribution of individual species have been incidentally mentioned. In the present state of our knowledge it is impossible to indicate, with any degree of certainty, the factors which determine the distribution of many of our important species.

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# EXPLANATION OF THE FIGURES.

## PLATE I.

*Fig.* 1. Germinating acorn of *Quercus incana*. (*a*), the short shoot of the young seedling bearing small scale-like leaves (*b*) (*b*). (*c*), the primary root which here becomes a vigorous tap-root. (*e*) (*e*), the secondary lateral roots, (*d*), the petioles of the cotyledons. The latter in this case are thick and fleshy and remain inside the acorn, below the ground, in germination.

„ 2. Seedling of *Quercus incana* with the cotyledons (*e*) removed from the acorn, otherwise lettering as before

„ 3. Young wheat plant. (*a*), wheat-grain from which the plant has sprung and which contains the single cotyledon ; (*d*), stem bearing green leaves (*e*) ; (*b*) and (*c*) roots. In this case there is no vigorous primary root forming a tap-root, and a number of roots of approximately equal vigour (*b*) (*b*). are found springing from the base of the stem (*d*). Vigorous young adventitious roots (*c*) (*c*) have also subsequently developed higher on the stem (*d*), just below the green leaves. The active roots and their branches are seen to have particles of soil clinging to them which are adhering firmly to the living roots-hairs, but the elongating tips of the roots (*f*) (*f*) have no root-hairs, and are free of soil particles, as are also most of the older roots (*b*) (*b*) and their branches, their root-hairs having died off, and they themselves having ceased to grow.

„ 4. Base of a stem of Sugarcane showing adventitious roots (*a*) (*a*) springing from the stem ; (*b*), a bud.

All the figures $\times \frac{1}{1}$.

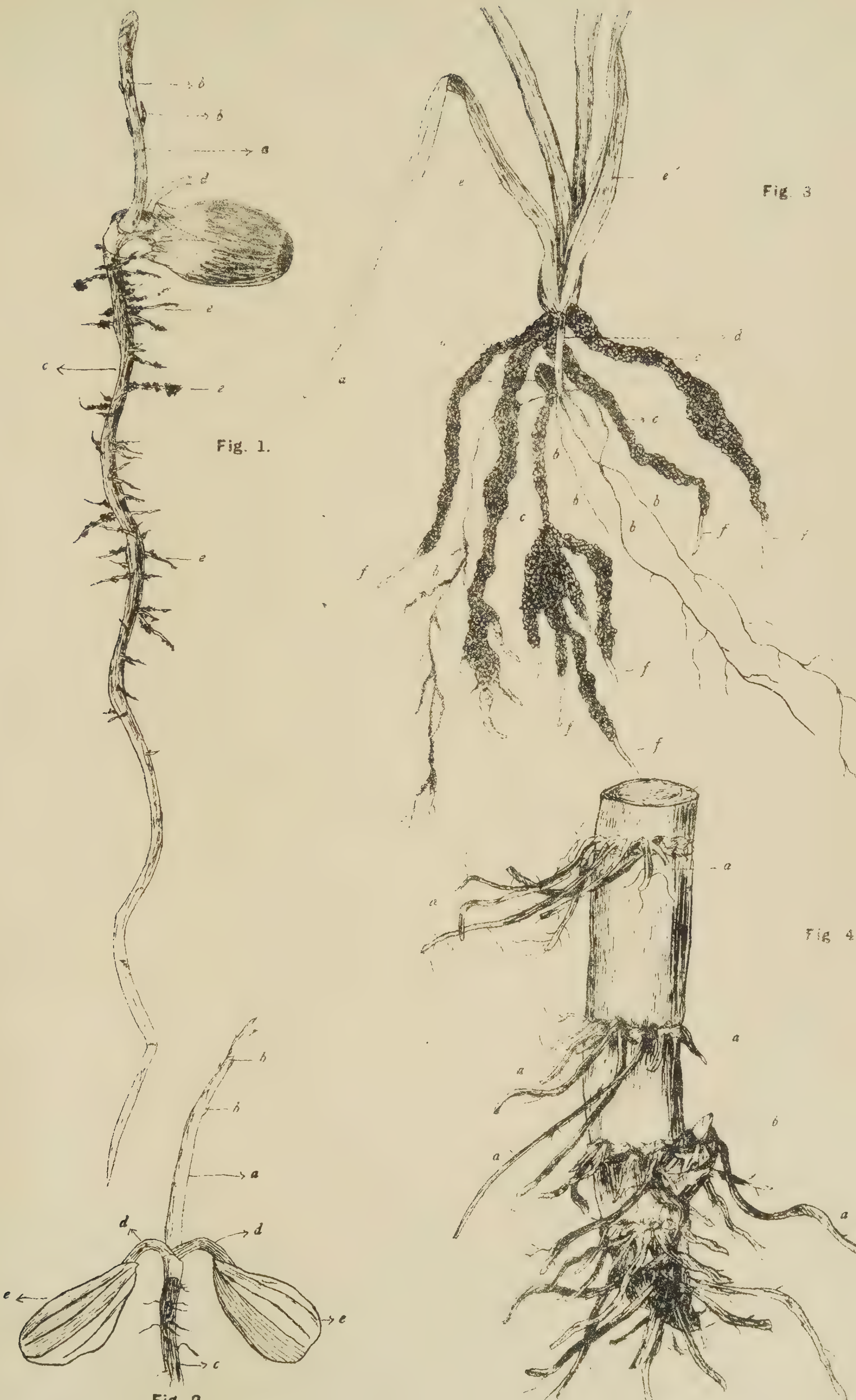


PLATE I.

# EXPLANATION OF THE FIGURES.

## PLATE II.

*Fig.* 1. Diagramatic plans showing the course followed by twining stems. (*a*), *dextrorse* stem moving in a *counter* - or *anti-clockwise* direction; (*b*), *sinistrorse* stem moving in a *clockwise* direction, *i.e.*, in the direction followed by the hands of a clock or watch.

,, 2. Diagrams showing (*a*) monopodial branching; (*b*), sympodial branching. In (*c*), the sympodium, or false axis, has become straightened and has a superficial resemblance to a monopodium. (*d*) (*d*), lateral branches springing from the leaf-axils.

,, 3. Twigs of *Pyrus Pashia* showing the relative development of shoots produced in one year. $\times \frac{3}{4}$.

Some of the buds (*a*) (*a*) have remained dormant, others have produced dwarf spineless shoots (*b*) (*b*), others have produced dwarf spiny shoots (*c*) (*c*), and others have produced long branches (*d*) (*d*).

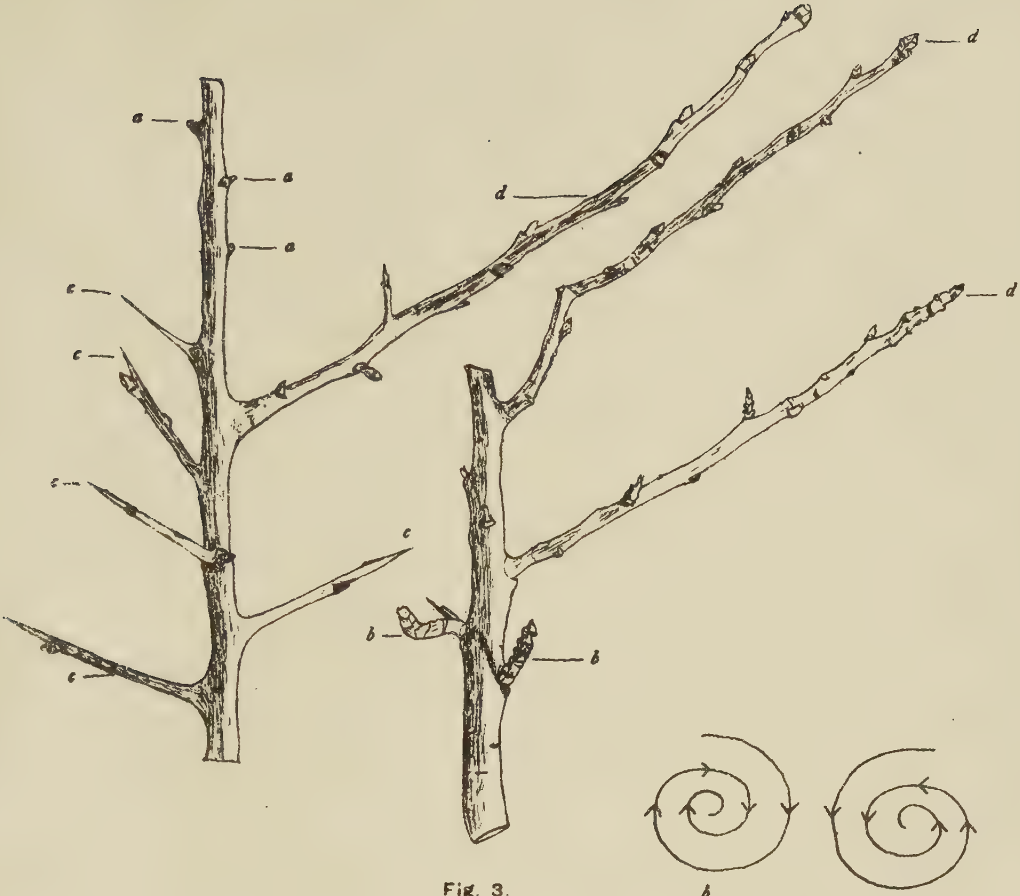


Fig. 3.

Fig. 1.

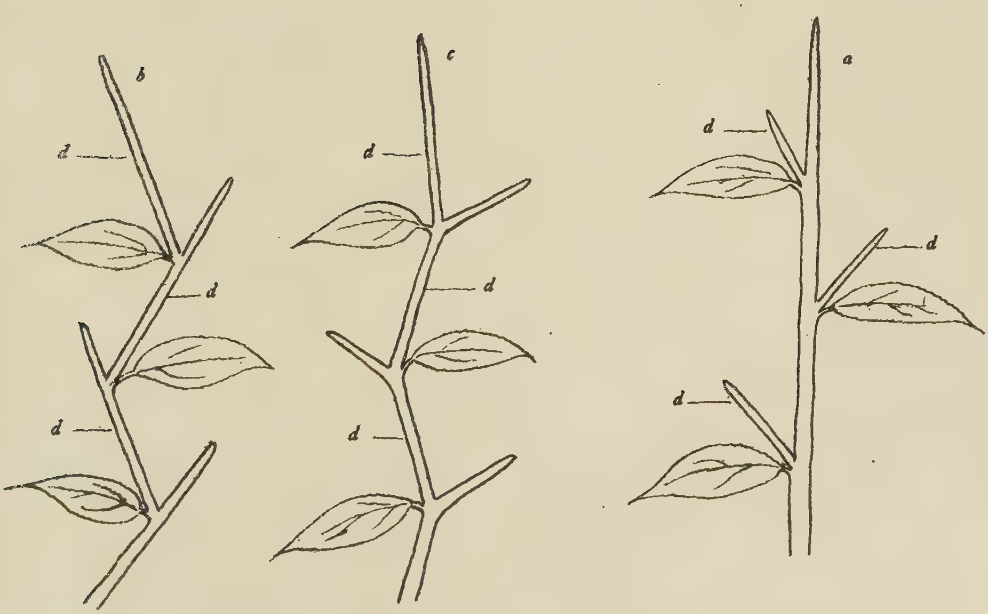


Fig 2.

PLATE II

# EXPLANATION OF THE FIGURES.

## PLATE III.

*Fig.* 1. (*a*). Spine of *Aegle Marmelos*. The spine arises in the axil of the trifoliolate leaf (*b*) and at its apex bears a rudimentary leaf (*c*), thus indicating that it is a branch. $\times \frac{1}{1}$.

" 2. (*a*). Compound spine of *Flacourtia Cataphracta* bearing three normal green leaves (*b*) (*b*) and thus indicating that it is a branch. $\times \frac{1}{1}$.

" 3. Stem of *Gouania leptostachya*. The tendrils (*a*) (*a*) arise in the axils of the leaves (*b*) (*b*), and they themselves frequently give rise to normal leaves as at (*c*), thus indicating that they are branches. $\times \frac{1}{2}$.

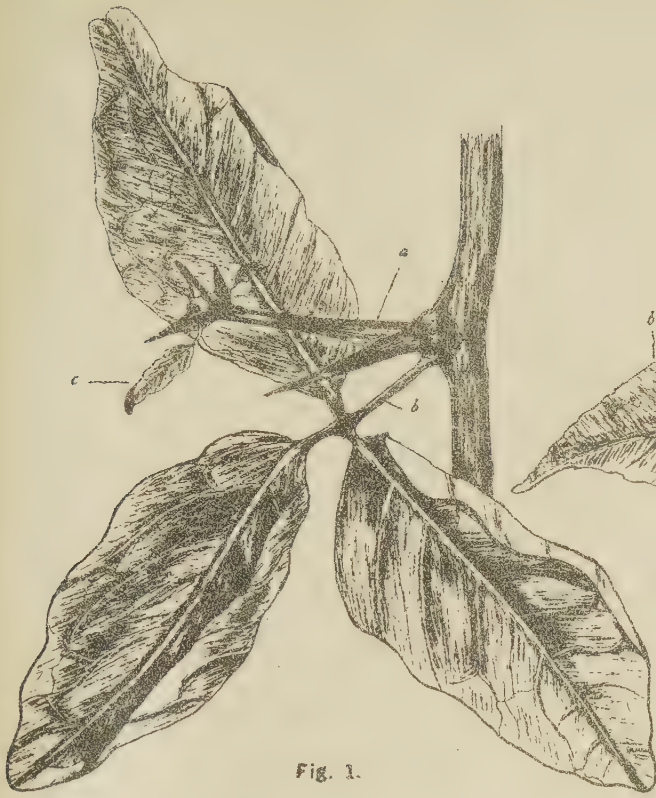

Fig. 1.

Fig. 2.

Fig. 3.

PLATE III.

## EXPLANATION OF THE FIGURES.

### PLATE IV.

*Fig.* 1. Penninerved leaf of *Quercus incana.* (*a*), midrib ; (*b*), straight secondary nerves ; (*c*), reticulate tertiary nerves. $\times \frac{2}{3}$.

" 2. Palminerved leaf of *Acer cæsium* with straight primary nerves. $\times \frac{2}{3}$.

" 3. Penninerved leaf of *Cornus macrophylla* with arcuate secondary nerves. $\times \frac{2}{3}$.

" 4. Leaf of *Smilax parvifolia* with curved basal nerves. $\times \frac{1}{1}$.
(*a*), broad leaf base; (*b*), tendrils.

" 5. Penninerved leaf of *Cinnamomum Camphora.* (*a*), strongly developed pair of lateral nerves. $\times \frac{1}{1}$.

" 6. Portion of leaf-blade of a Fern. (*a*), midrib from which spring furcate lateral nerves. $\times \frac{1}{1}$.

" 7. Pedately-parted leaf of *Delphinium*. $\times \frac{1}{1}$.

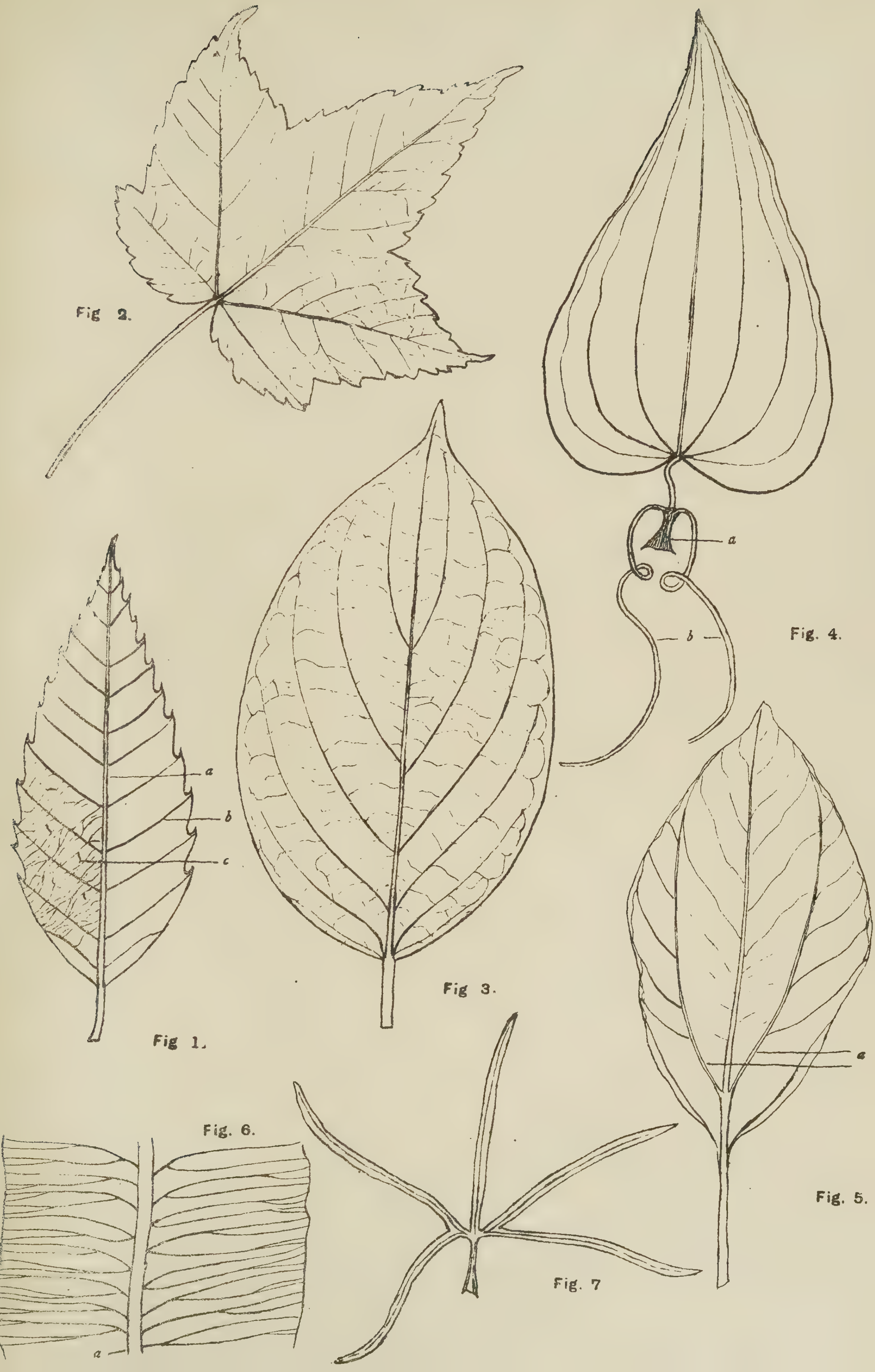


PLATE IV.

# EXPLANATION OF THE FIGURES.

## PLATE V.

*Fig.* 1. Pinnately trifoliolate leaf of *Desmodium tiliæfolium.* (*a*) (*a*), petiolules of leaflets; (*b*) (*b*), stipels; (*c*), rhachis; (*d*), petiole. $\times \frac{1}{1}$.

„ 2. Palmately 5-foliolate leaf of *Holboellia latifolia;* (*a*) (*a*), petiolules; (*b*), petiole. $\times \frac{3}{4}$.

„ 3. Upper portion of pinnate leaf of *Berberis nepalensis*; (*a*), rhachis. Note the distinct joint (*b*) at the base of the terminal leaflet and at the insertion of the lateral leaflets. $\times \frac{1}{2}$.

„ 4. Leaf of *Berberis Lycium.* Note the distinct joint (*a*) between the leaf-blade and leaf-base. $\times \frac{1}{1}$.

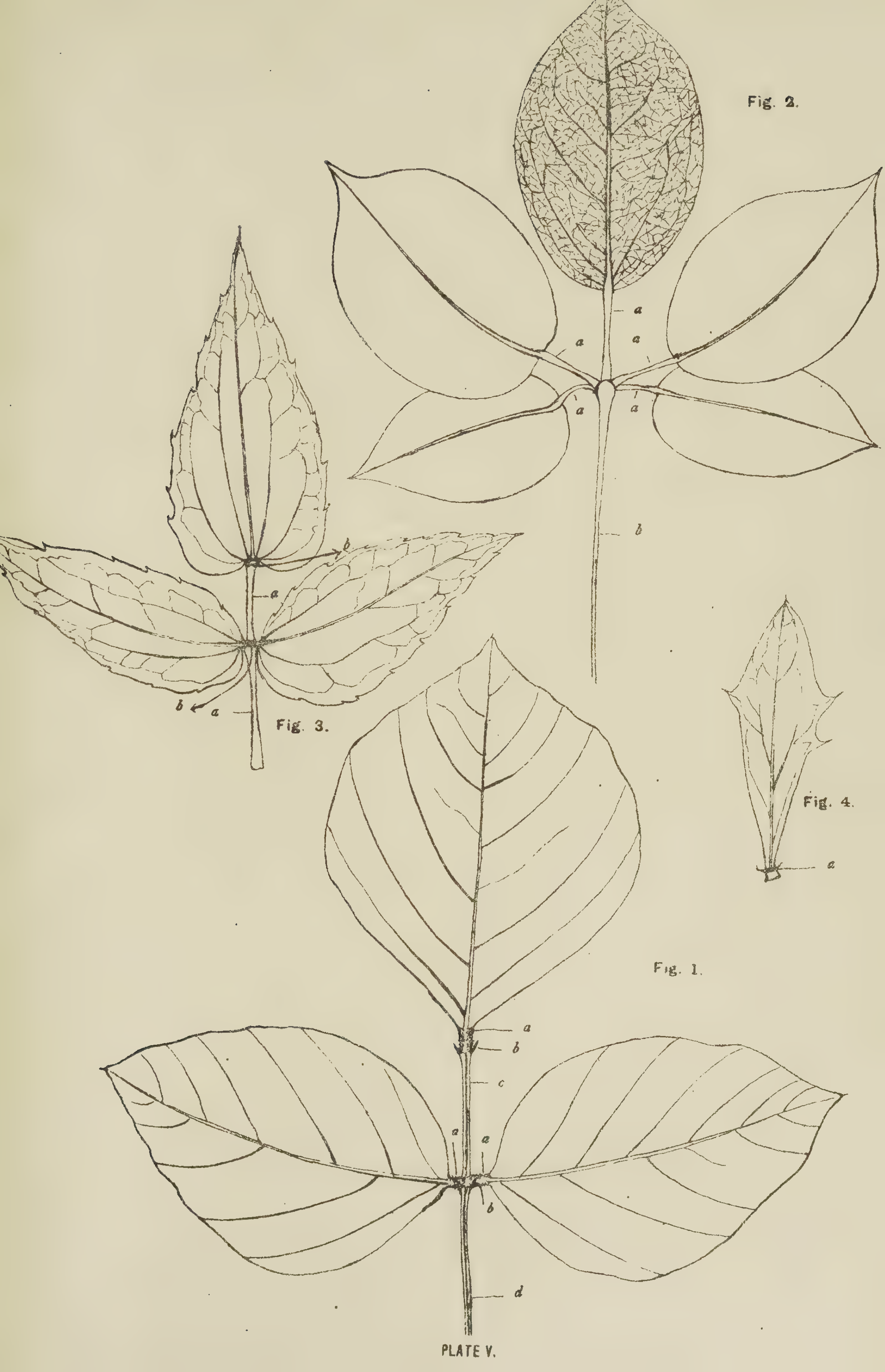


PLATE V.

## EXPLANATION OF THE FIGURES.

### PLATE VI.

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*Fig.* 1. Creeping stem of Ivy (*Hedera Helix*) with aerial roots (*a*). Note great variety in the shape of the leaves. $\times \frac{2}{3}$.

" 2. Erect fruiting branch of Ivy. Note how the leaves differ from those in Fig. 1. $\times \frac{1}{2}$.

" 3. Stem of *Berberis Lycium*. $\times \frac{1}{2}$.

(*a*), normal leaf in the axil of which a shoot bearing two small leaves is developing. Note the minute stipules at (*d*) ; (*b*), a three-pronged spine which is really a leaf as indicated by the fact that a leafy branche is developing in its axil. Note the minute stipules still visible at (*e*).

(*c*), a three-pronged green leafy structure intermediate between the normal leaf (*a*) and the spine (*b*). The leaf-nature is revealed by the presence of the leafy branch in its axil. Note also its minute stipule at (*f*).


PLATE VI.

# EXPLANATION OF THE FIGURES.

## PLATE VII.

*Fig.* 1. Twig of *Acer cæsium* from the terminal bud of which four leaves have developed. At (*a*) (*a*) the bases of the petioles of 3 leaves which have been cut off are shown. (*b*), scars marking the position of the bud-scales which have just been shed. (*c*) (*c*), scars marking the position of the bud-scales which have similarly been shed at the beginning of the annual growth in previous years. The twig thus shows the completed growth of 3 years and is just commencing its 4th year's growth.

„ 2. Twig of *Carpinus viminea* which has just commenced its annual growth. (*a*) to (*b*), part of the winter twig; (*b*) to (*c*), part of the spring shoot which has just developed from the terminal bud of the winter twig. At (*b*), the lowest brown bud-scales have fallen off, but the pair of scaly stipules at (*d*), which flank the petiole of the lowest leaf, were actually present as bud-scales in the winter-bud, and at their tips the dark brown portions which were exposed on the outside of the winter-bud are still visible At (*e*) (*e*), the stipules are larger, but in them also the dark portions which were exposed in the winter-bud are still visible. At (*c*), the stipules are normal and no dark portions are visible. In this case the bud-scales are obviously modified stipules.

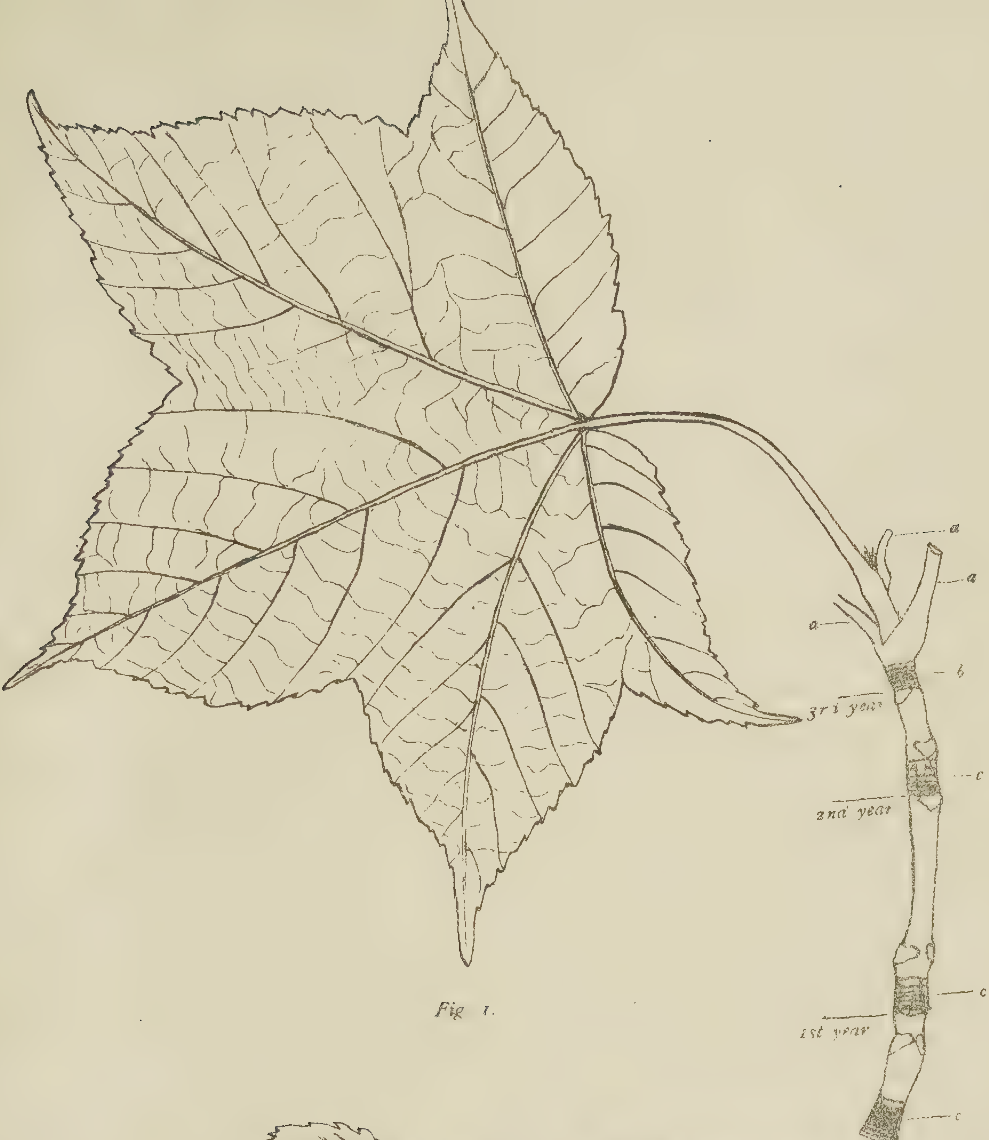


Fig. 1.


Fig. 2.

PLATE VII.

# EXPLANATION OF THE FIGURES.

## PLATE VIII.

*Figs.* 1—8. Showing the transition from an obvious bud-scale (1), taken from the exterior of the bud, to a normal leaf (8), taken from the interior of the bud, observed in an opening bud of the Horse Chestnut (*Aesculus indica*), indicating that the winter bud-scales are really leaves which have been checked in their development at an early stage and converted into protective coverings for the bud. Minute points representing the rudimentary leaflets are recognisable at the tips of the scales (1) to (4). × $\frac{1}{1}$.

" 9. Young shoot of *Stephegyne parvifolia*. (*a*), base of petiole of leaf which has been cut off to show the large interpetiolar stipules (*b*) (*b*). The terminal bud is concealed and protected by the stipules, one of which (*c*) is facing the observer. × $\frac{1}{1}$.

" 10. Stem of *Prinsepia utilis*; (*a*), leaf in the axil of which is situated a bud (*b*) and also a stout spine (*c*), the latter protecting the bud (*b*). (*d*) (*d*), other axillary buds, the subtending leaves of which have fallen off. At (*e*), the axillary bud has produced a leafy shoot. One of the spines bears a leaf (*f*) showing the spines to be branches. × $\frac{1}{1}$.

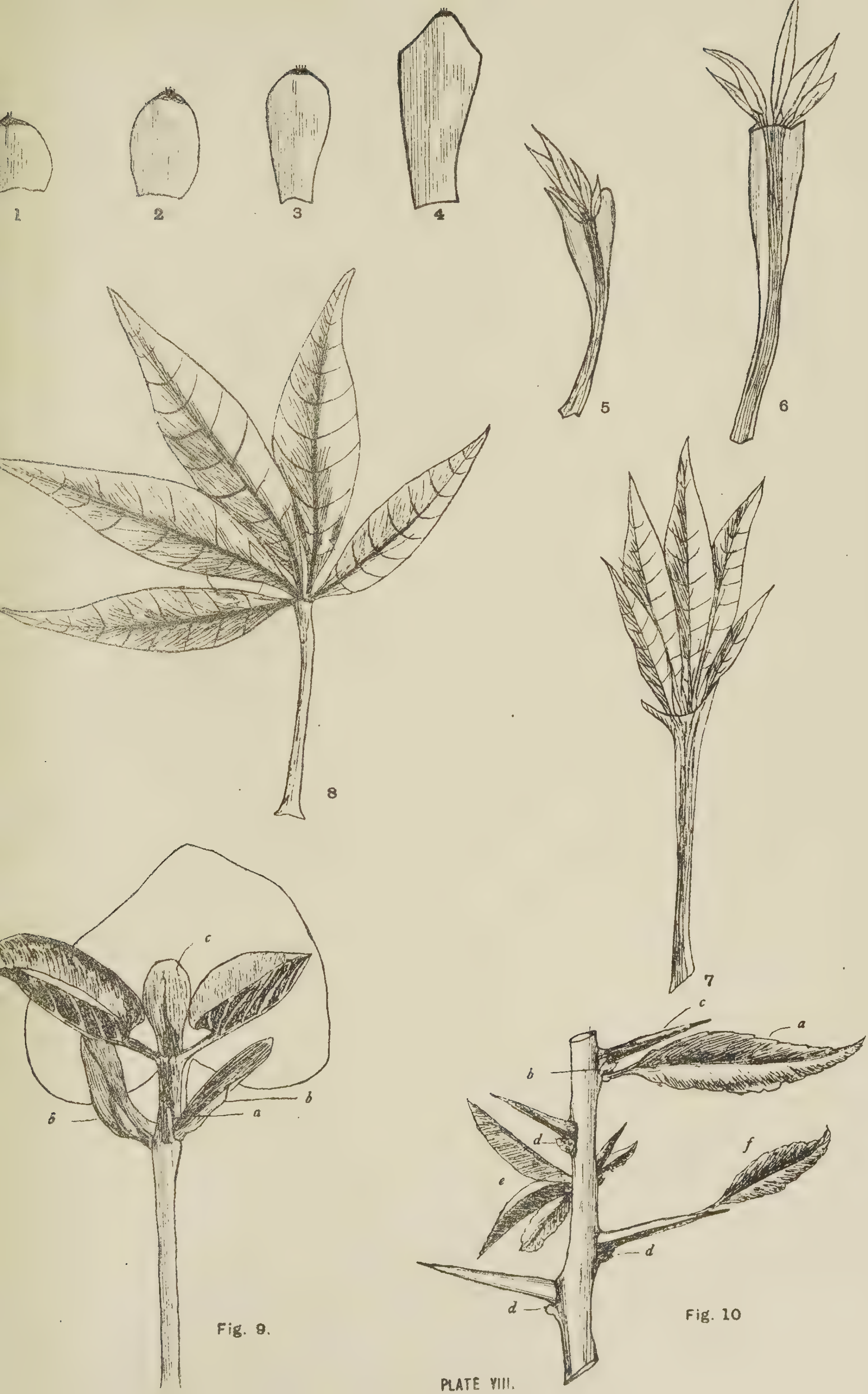


PLATE VIII.

## EXPLANATION OF THE FIGURES.

### PLATE IX.

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*Fig.* 1. Diagram of involute vernation.
„ 2. „ revolute „
„ 3. „ conduplicate vernation.
„ 4. „ convolute „
„ 5. „ circinnate „
„ 6. „ plicate „

(*a*) (*a*) throughout is the midrib; (*b*), the upper surface, and (*c*), the lower surface, or back of the leaf.

*Figs.* 7—9. Stages in the development of the leaves of *Viburnum cotinifolium*. The opposite leaves (*a*) (*a*), when very young, are erect, and with their upper surfaces in close contact, only the lower surface being exposed to the light and air. The lamina is plicately folded, and the delicate green tissue is protected by the close-set framework of nerves which alone are exposed on the lower surface. As development proceeds the folds of green tissue are flattened out and the leaf is thrown outward and downward, the upper surface being finally exposed to the full rays of the sun as in Fig. 9.

The petioles of the young leaves are grooved on their upper surface, so that space is provided for the terminal bud between them. In Fig. 8, (*b*) represents the terminal bud in cross section, and (*c*) (*c*) the closely adpressed petioles also in section.

Figs. 7 and 8 slightly enlarged, Fig. 9. × ½.

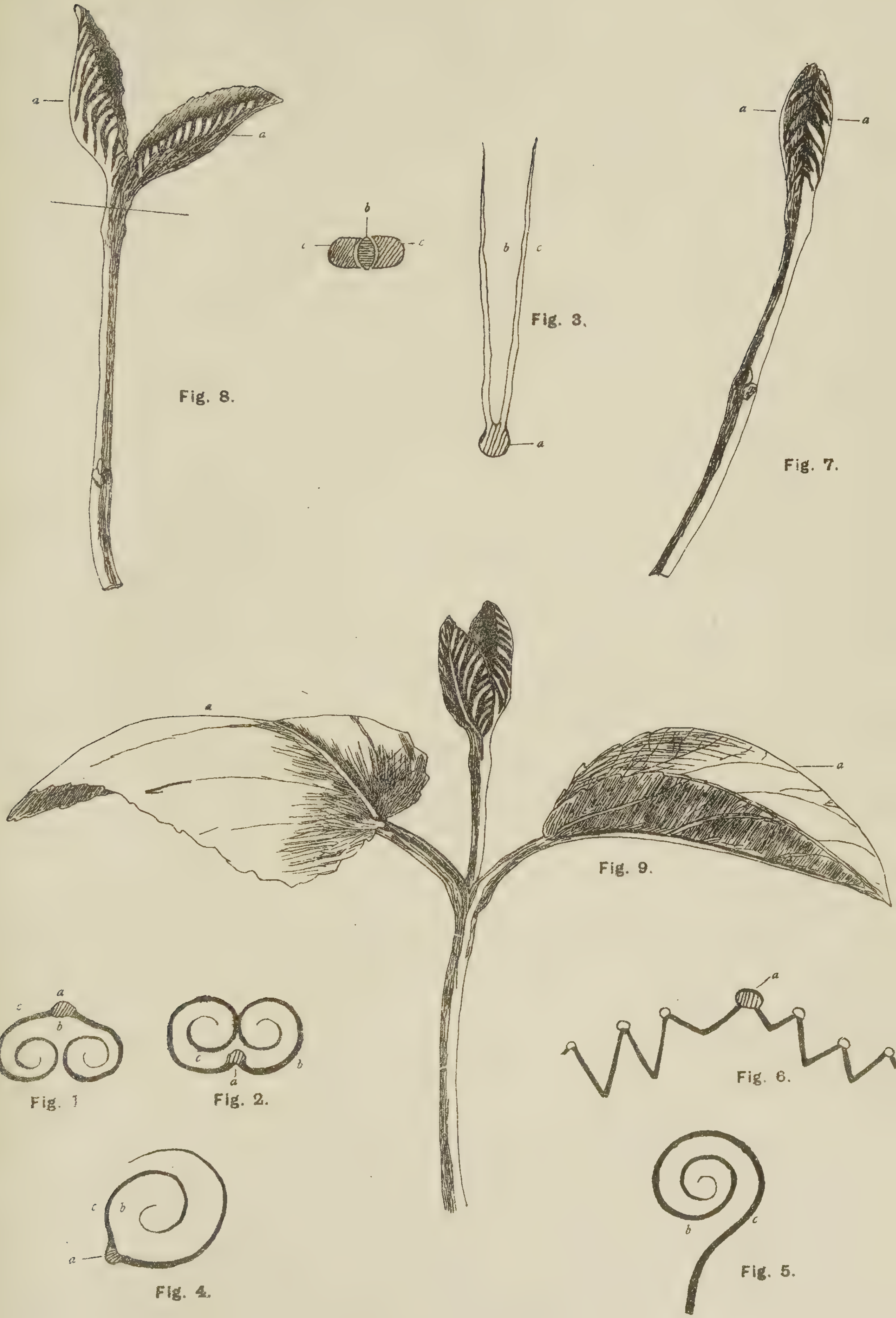



PLATE IX.

# EXPLANATION OF THE FIGURES.

## PLATE X.

*Fig.* 1. Diagram of a raceme.
,, 2. ,, ,, corymb.
,, 3. ,, ,, spike.
,, 4. ,, ,, umbel; (*c*), the involucre.
,, 5. ,, ,, head or capitulum; (*c*), the involucre.
,, 6. ,, ,, compound umbel; (*c*), involucre; (*d*) (*d*), umbellules; (*e*) (*e*), involucels; (*f*), rays.
,, 7. ,, ,, panicle.
,, 8. ,, ,, dichotomous cyme.
,, 9. ,, ,, helicoid ,,
,, 10. ,, ,, scorpioid ,,

Throughout (*a*) (*a*) are flowers; (*b*) (*b*), the bracts.

,, 11. Diagram of a hypogynous flower; (*a*), sepal; (*b*), petal; (*c*), stamen; (*d*), ovary.
,, 12. and 13. Diagrams of a perigynous flower—letters as before.
,, 14. Diagram of an epigynous flower—letters as before.
,, 15. ,, valvate— æstivation.
,, 16. ,, valvate—induplicate ,,
,, 17. ,, ,, involute ,,
,, 18. ,, of an imbricate ,,
,, 19. ,, contorted ,,

Overlap to the right.

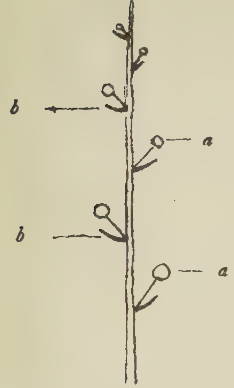



Fig. 1.

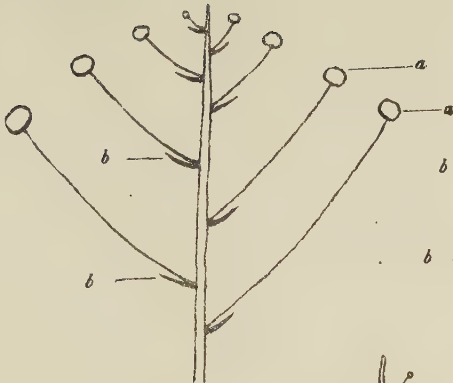



Fig. 2.

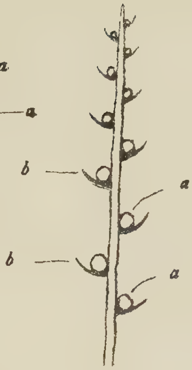



Fig. 3.

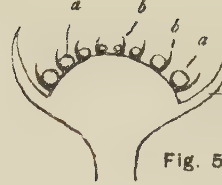



Fig. 5.

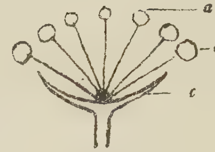



Fig. 4.

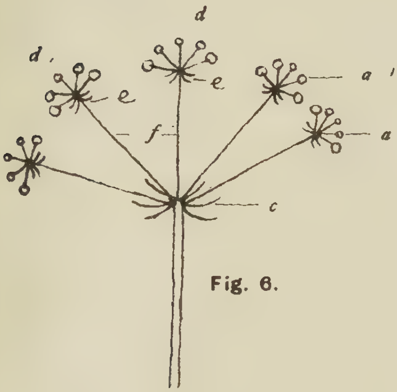



Fig. 6.

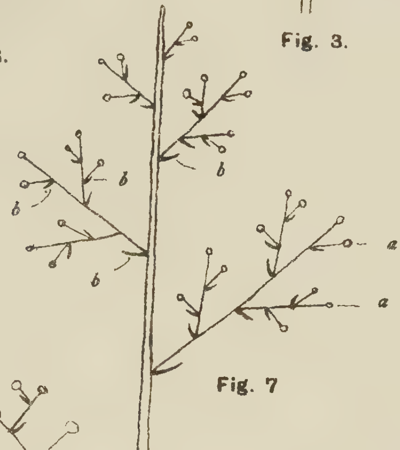



Fig. 7

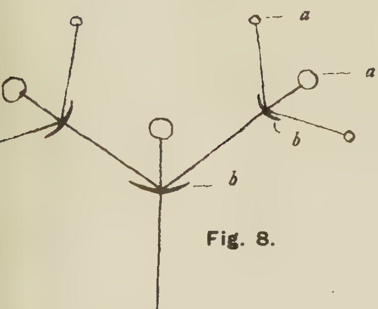



Fig. 8.

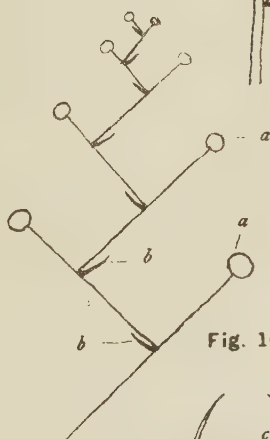



Fig. 10

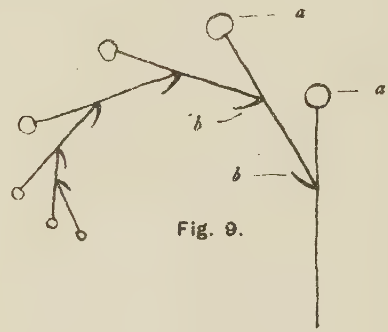



Fig. 9.

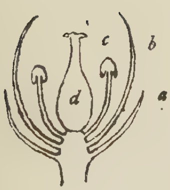



Fig 11


Fig 12

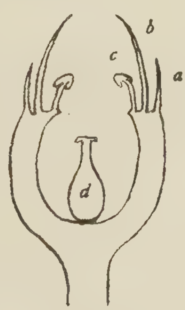



Fig. 13.


Fig. 14.

Fig. 15.

Fig. 16.

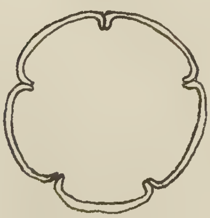


Fig. 17.

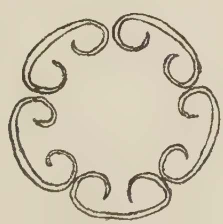


Fig. 18.

Fig. 19.

## EXPLANATION OF THE FIGURES.

### PLATE XI.

*Fig.* 1. Winter twig of *Odina Wodier.* (*a*), leaf-scars—note their shape and alternate arrangement.

" 2. Winter twig of *Hymenodictyon excelsum.* (*a*), leaf-scars—note their shape and opposite arrangement.

" 3. Photograph of *Bombax malabaricum.* Note the branches in whorls.

" 4. Photograph of *Bombax malabaricum* showing the woody buttresses at the base of the stem.

Fig. 2.


Fig. 4.

Fig. 3.

Fig. 1.


Plate XI.

# EXPLANATION OF THE FIGURES.

## PLATE XII.

*Fig.* 1. Seed of *Oroxylum indicum*. × $\frac{1}{1}$.
(*a*), membranous wing developed from the testa; (*b*), the embryo enveloped in the testa.

„ 2. Embryo of *Oroxylum indicum* extracted from the seed. × $\frac{1}{1}$.
(*a*), radicle; (*b*), lower surface of one cotyledon, its upper surface being placed flat against that of the opposite cotyledon, which is not visible in the drawing. The plumule also is not visible.

„ 3. Young seedling of *Oroxylum indicum*. (*a*), (*b*), the two cotyledons with their upper surfaces separating from each other; (*c*), the hypocotyl; (*d*), primary root; (*e*), secondary lateral roots. × $\frac{1}{1}$.

„ 4. The same at a later stage; (*f*), the minute terminal bud of the stem, otherwise letters as before. × $\frac{1}{1}$.

„ 5. The same at a still later stage; (*g*), the first pair of foliage leaves; *h*, the epicotyl, otherwise letters as before. × $\frac{1}{1}$.
The root not shown.


Fig. 5

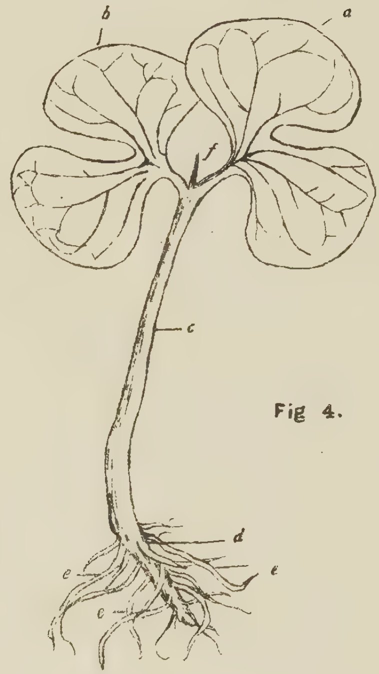



Fig 4.


Fig. 3.


Fig. 2.

Fig. 1.

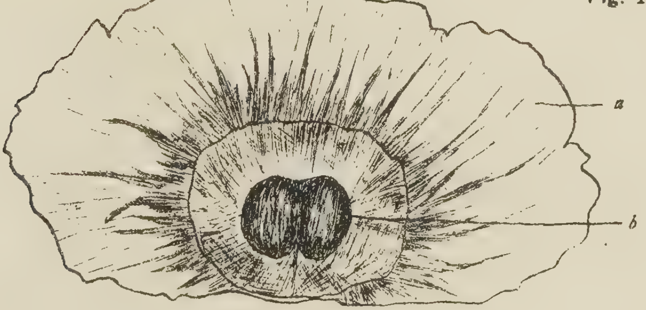



PLATE XII.

## EXPLANATION OF THE FIGURES.

### PLATE XIII.

*Fig.* 1. Erect branch of *Coriaria nepalensis* seen from the side. × ½.

Note the decussate leaves arranged in four ranks on the 4-angled stem with their upper surfaces at right angles to the rays of light coming from above. The stem is not twisted.

„ 2. Horizontal branch of *Coriaria nepalensis*, seen from above. × ½.

Note the distichous leaves with their upper surfaces practically horizontal and at right angles to the rays of light coming from above. Also the twisting of the 4-angled stem caused by the efforts of the leaves to place themselves at right angles to the incident rays of light.

In both figures one side of the 4-angled stem is shown shaded throughout.

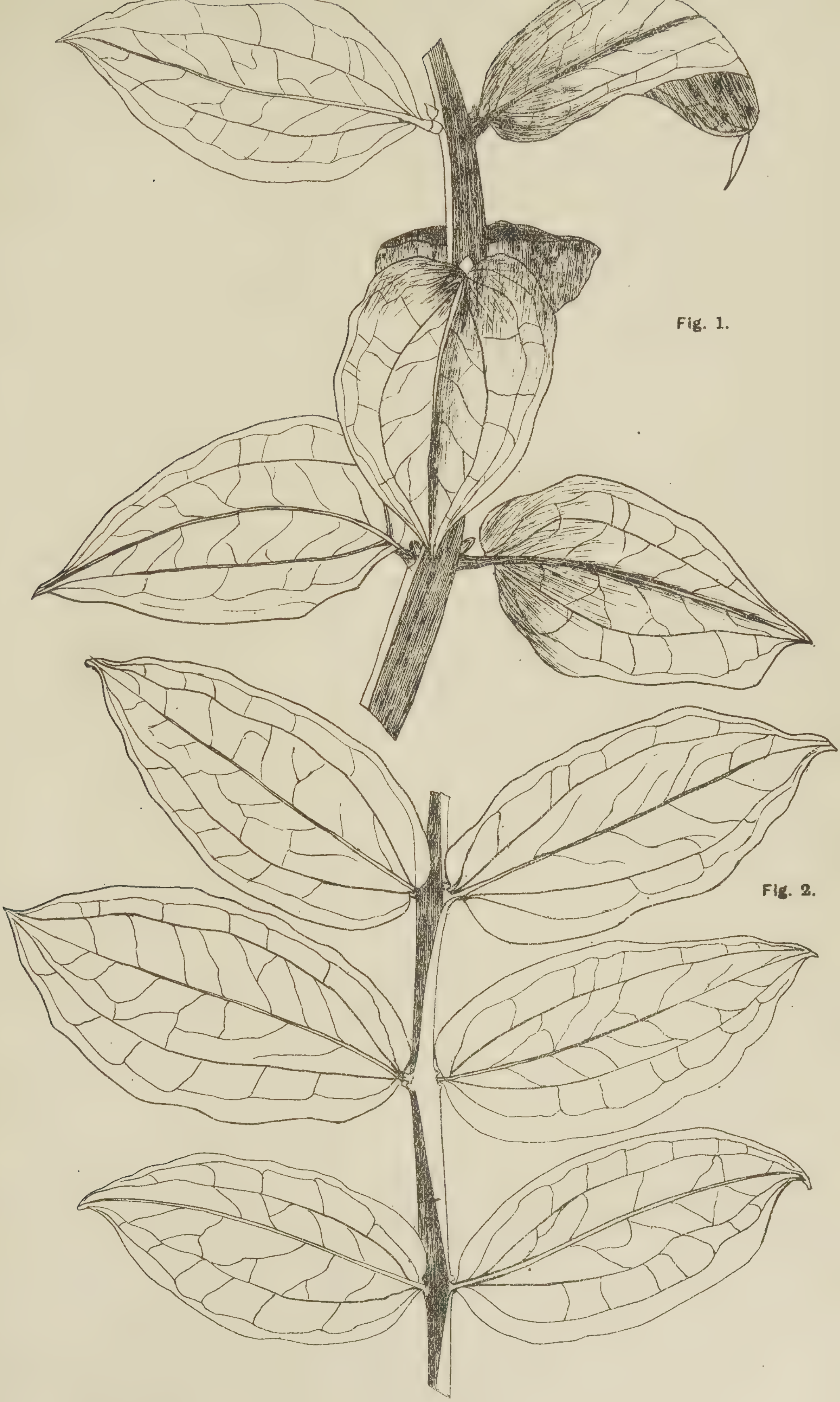



PLATE XIII.

## EXPLANATION OF THE FIGURES.

### PLATE XV.

*Fig.* 1. (*a*). *Barclayella deformans* on *Picea Morinda*. × $\frac{1}{1}$. Note the orange-red curved needles on the attacked shoot and compare them with the straight healthy needle shown below.

(*b*). Cone scale of *Picea Morinda* attacked by the *Barclayella*, showing the beds of teleuto-spores. × $\frac{1}{1}$.

„ 2. *Peridermium brevius* on *Pinus excelsa*. Note the reddish-yellow blisters. The needles have been cut short for convenience. × $\frac{1}{1}$.

„ 3. Teleuto-form of *Gymnosporangium Cunninghamianum* on *Cupressus torulosa*. Note the gelatinous spore-masses. × $\frac{1}{1}$.

„ 4. Aecidium form of *Gymnosporangium Cunninghamianum* on *Pyrus Pashia*. Note the tubular *aecidia*. × $\frac{1}{1}$.

„ 5. *Gambleola cornuta* on *Berberis nepalensis*. Note the black hairs of teleuto-spores. × $\frac{1}{1}$.

(All after Butler).

Fig. 4.

Fig. 3.

Fig. 5.

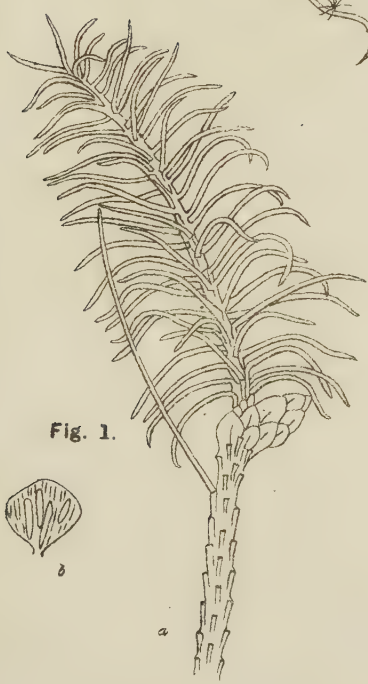



Fig. 1.

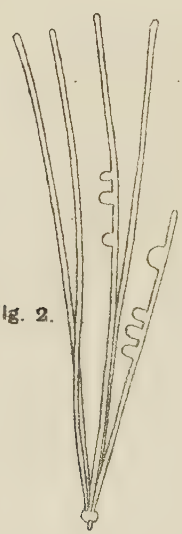


Fig. 2.

PLATE XV.

## EXPLANATION OF THE FIGURES.

### PLATE XVI.

*Phytophthora infestans.*

*Fig.* 1. Back of potato leaflet attacked by the fungus showing the characteristic dark spots with pale mouldy margins.

" 2. Conidiophores bearing conidia emerging from a stoma on the underside of a leaflet. Highly magnified.

" 3. Conidium with protoplasm divided into blocks, the latter being liberated as zoospores in *Fig.* (4).

" 5. Zoospore coming to rest and losing its cilia.

" 6. A zoospore which has germinated.

" 7. A conidium which has germinated directly and sent out a germ-tube.

*Figs.* (3), (4), (5), (6) and (7) very highly magnified.


PLATE XVI.

PHYTOPHTHORA INFESTANS.

# EXPLANATION OF THE FIGURES.

## PLATE XVII.

*Fig.* 1. Sporophore of *Fomes annosus* on deodar showing the brown tuberculate incrustation, and bracket-like active portion with white hymenium below; *a*, *a*, brown, mostly sterile portion; *b*, *b*, recent spore-forming portion.

„ 2. White mycelial sheets under the bark of the collar.

„ 3. Drawing of a portion of the surface of a block of wood cut from a diseased tree, showing the white areas in the wood.

„ 4. Tissue elements modified by the action of the parasite. *a*, *a*, cells of the wood parenchyma-bearing starch; *b*, bore-holes of the hyphæ with a filament extending across between two; *c*, spiral cracking of the wall; *d*, pitted vessel with a hypha penetrating it; *e*, network from the crossing of two spirals, the trachea is seen with the upper wall removed so that the network is made up of the spiral of the lower wall of this trachea and that of the upper wall of the subjacent one; *f*, dissolution of the middle lamella which results in the isolation of the elements.

„ 5. A rhizomorph.

(All after Butler).

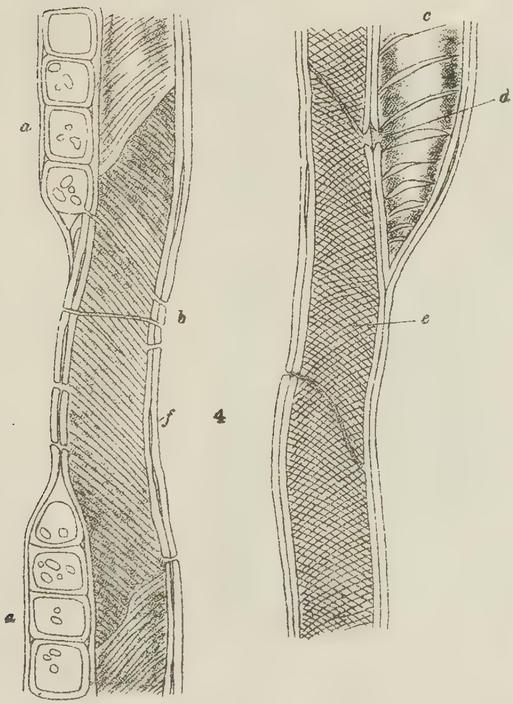

PLATE XVII.

Fig. I.

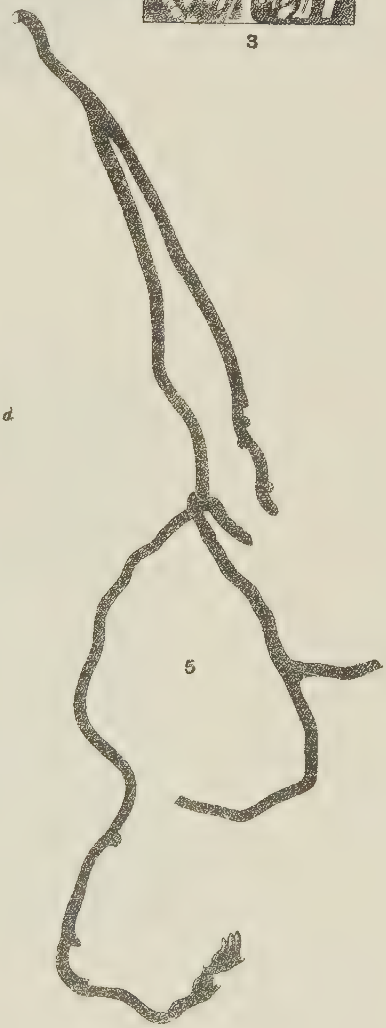
FOMES ANNOSUS. Fr.

2

3




4

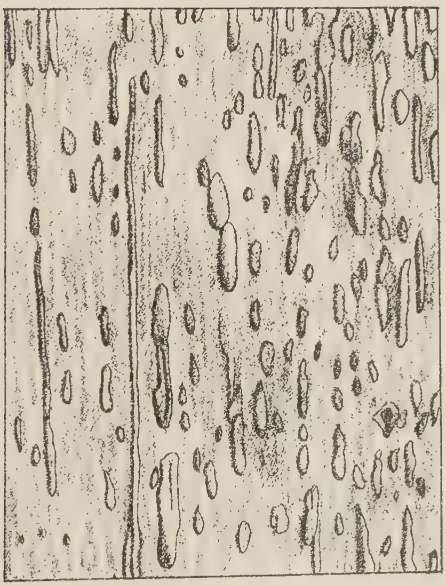


5

PLATE XVII.
Figs. 2–5

FOMES ANNOSUS, Fr.

(a)



(b)

PLATE XVIII.

**TRAMETES PINI, FRIES.**

(*a*). Sporophore.

(*b*). Wood of Pinus excelsa rotted by the fungus.

(After Butler).

# EXPLANATION OF THE FIGURES.

## PLATE XIX.

*Puccinia graminis.* Pers.

*Fig.* 1. Wheat stem and leaf with *teleuto-spores.* × $\frac{1}{1}$.

,, 2. *Ureao-spores.* The one on the right has developed two germ-tubes. Highly magnified.

,, 3. *Teleuto-spores.* The one on the right has germinated, the upper cell producing a *pro-mycelium* (*a*) from which spring *sterigmata*, bearing *sporidia* (*b*). Highly magnified.

,, 4. Under-surface of leaf of *Berberis Lycium* showing the *æcidia* on a dark brown patch. × $\frac{1}{1}$.

,, 5. An open aecidium from above. Magnified.

,, 6. Transverse section of *Berberis* leaf. (*a*), is lower surface of leaf. Two æcidia are shown, one of which has not yet burst through the leaf epidermis. Highly magnified.


PLATE XIX.

PUCCINIA GRAMINIS PERS.

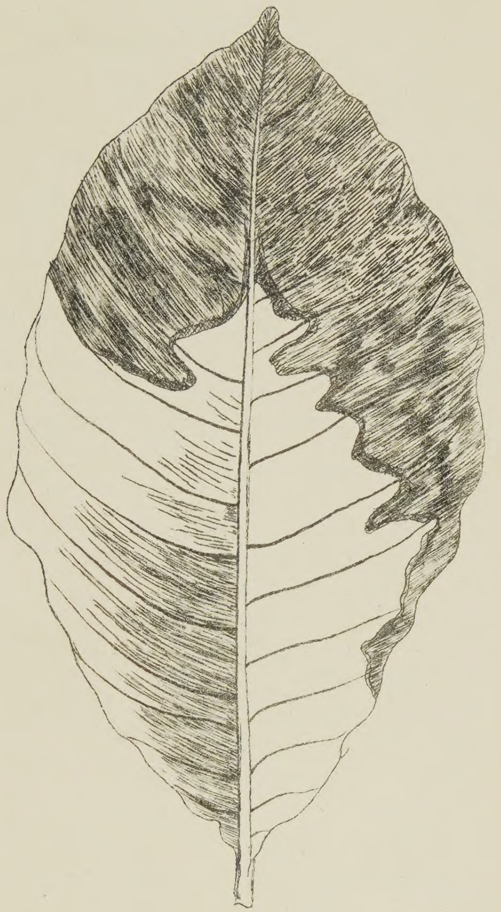


PLATE XX.

LEAF OF A YOUNG MAHUA PLANT (BASSIA LATIFOLIA) INJURED INDIRECTLY BY FROST. ×½.

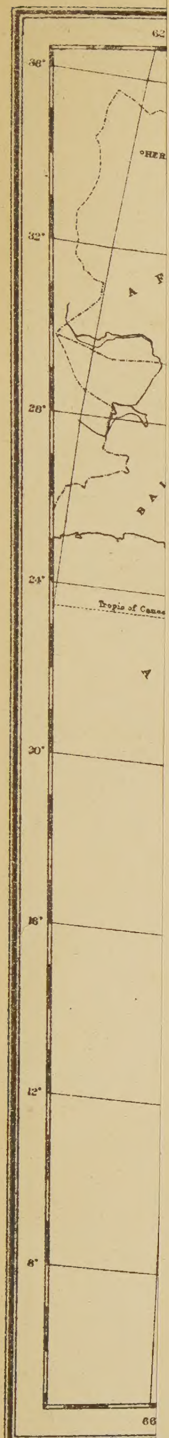



Photo.-Mechl. a